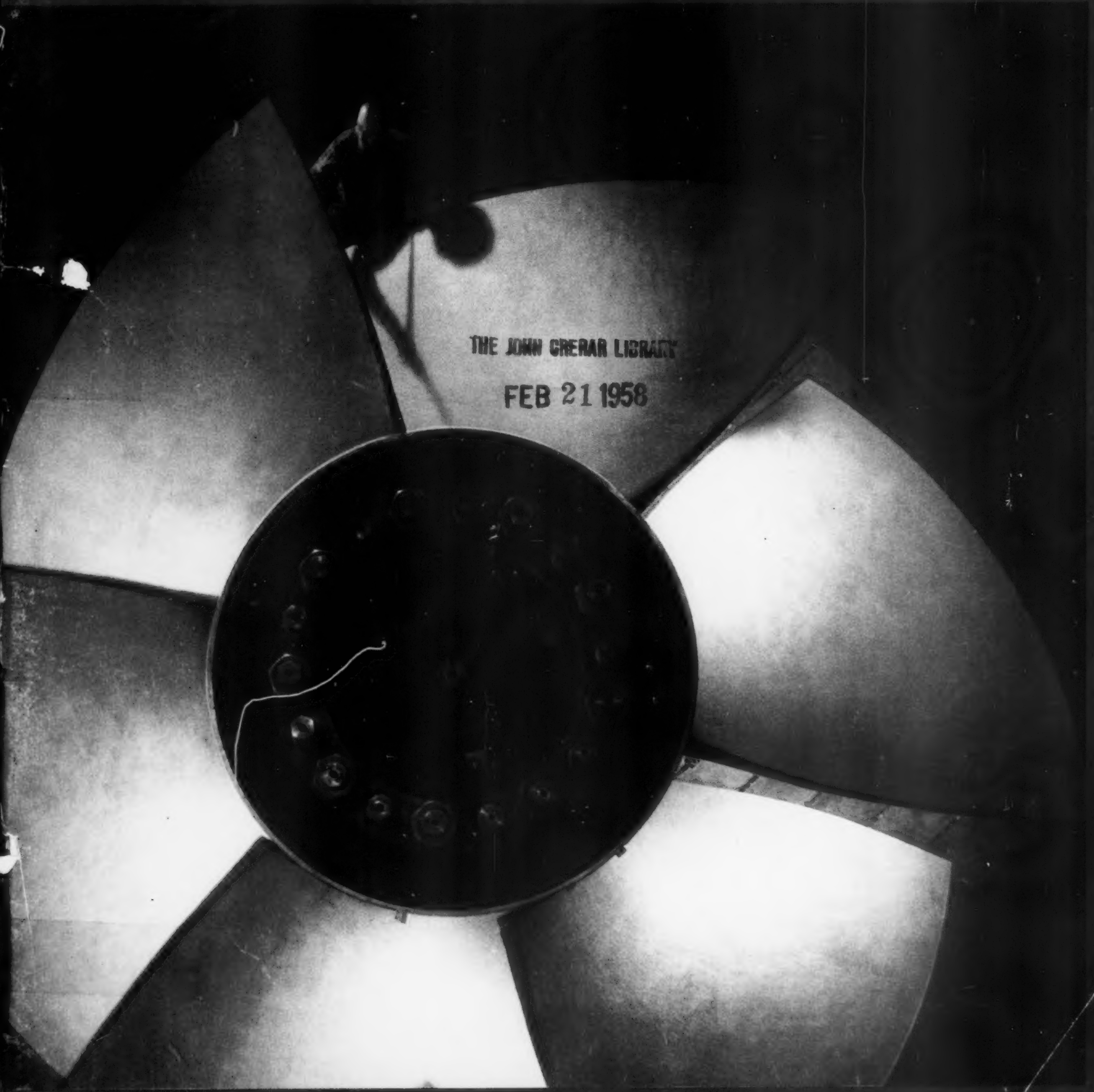
ALLIS-CHALMERS Electrical REVIEW

4TH QUARTER 1957



ALLIS-CHALMERS
Electrical REVIEW

THE COVER

FIXED-BLADE 240-in. diameter propeller runner will deliver 79,000 hp under 81-ft head for Unit No. 4 of eight Allis-Chalmers hydraulic turbines to be used in the St. Lawrence Power Project, scheduled for completion in 1958 and 1959. See photo on page 14.

Allis-Chalmers Staff Photo by Mike Durante

Allis-Chalmers

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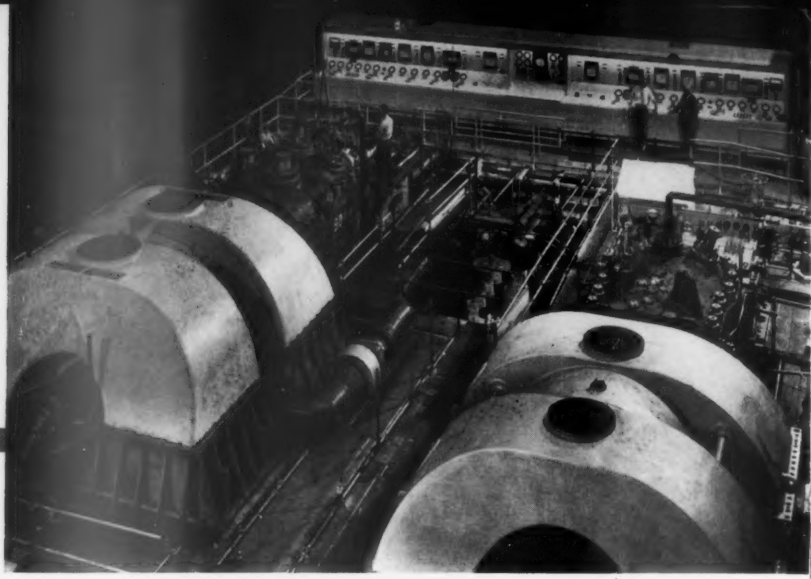
COPING WITH REHEAT TURBINE OVERSPEED



TWO OF THE FIRST turbines to incorporate an electrical load dump anticipator are shown being assembled and tested simultaneously. The tandem-compound 3600-rpm reheat units are rated 150 and 100 mw.

by **C. L. RINGLE**
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New overspeed and trip-out control for 3600-rpm reheat steam turbine-generators anticipates effect of sudden load dump.

INCREASING THE OVERALL EFFICIENCY of high pressure, high temperature 3600-rpm reheat turbine-generator units has resulted in an increasing ratio of power output to rotational inertia, WR^2. This changing ratio is causing greater concern about overspeed and trip-out control.

One phase of the overspeed problem involves the control of turbine-generator overspeed levels caused by the accelerating potential of large steam volumes stored in the reheater system and extraction heaters, including stored flashable condensate. The other phase is holding the speed rise of the unit below the trip-out level, following an instantaneous loss of capability load. This part of the problem can be divided into two types:

(1) The possibility of trip-out produced by high initial acceleration rates.

(2) The possibility of trip-out produced by the slower accelerating action of pressurized steam leakage through the reheat diaphragm and balance piston seals.

On certain system arrangements, where a solenoid-actuated trip-out of all steam inlet controls is permissible following relay or circuit breaker action, the initial acceleration problem is of no consequence.

The normal reasons for a solenoid-actuated trip-out are: low vacuum, low bearing oil pressure, failure of turbine thrust bearing, and certain electrical system faults. All other trip-out causes should be minimized for maximum station operating efficiency.

Overspeed possibilities can be calculated

The maximum turbine-generator speed level attained following a full-load dump associated with a possible malfunctioning of the steam inlet or reheat controls is a function of the quantity of system stored steam, condensate in the heaters, and the rotational inertia of the machine's rotors. These quantitative items determine the possible transfer of thermal energy into rotational kinetic energy. This energy conversion is evaluated by the equation

$$\Delta H' = \Delta KE = \frac{WR^2}{4.57 \times 10^6}(N_2^2 - N_1^2)$$

where $\Delta H'$ = usable thermal energy transferred, Btu.

ΔKE = kinetic energy change of rotating elements, Btu.

WR^2 = rotational moment of inertia, lb-ft^2.

N_1 = initial speed, rpm.

N_2 = final speed, rpm.

The possible occurrence of control malfunctioning could result in maximum overspeed levels of as much as 40 to 55 percent on many modern tandem reheat turbine installations. This general situation became apparent several years ago.

The possibility of excessive overspeed is reduced to the status of improbability by use of a conventional pair of parallel intercept valves which are backed up with a "second line of defense" by a pair of parallel reheat stop valves in the hot reheat steam lines. This is similar to the governor-controlled inlet valves and high pressure stop valves, in series, to give two lines of defense.

The intercepts are controlled by a speed-governor- modulated pressure-control oil system which starts the closing action at approximately 1.5 percent overspeed and produces full closing at 3 percent overspeed. The reheat stop-valves are closed by the turbine trip-oil system when a unit overspeed level in excess of 10 percent is attained. If an intercept valve closing failure should occur, in conjunction with a load dump, the reheat stop-valves closing limits the

overspeed level of low-inertia tandem machines to approximately 15 percent maximum.

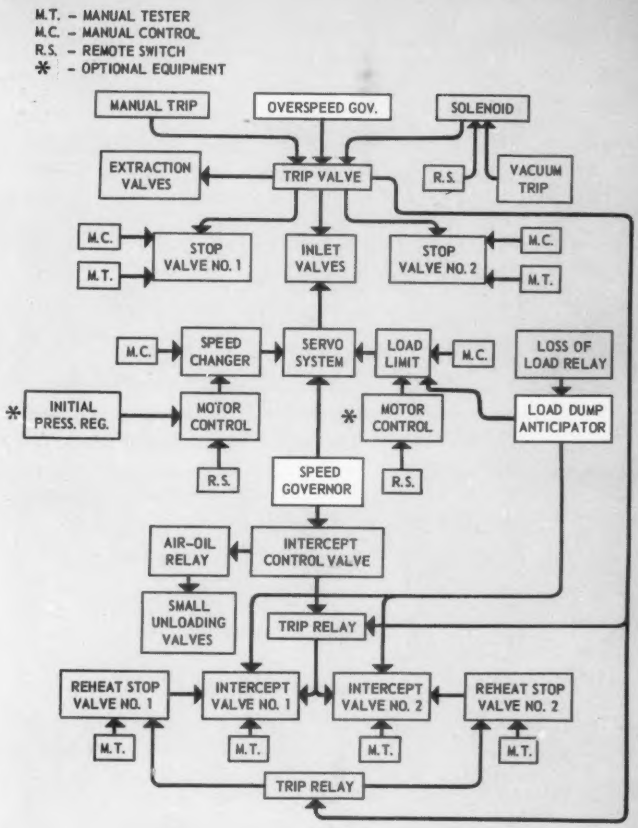
The higher overspeed levels possible, resulting from the stored steam and hot condensate in the feed-water heaters, is controlled by the use of positive-closing non-return check valves in the extraction lines between the turbine and the heaters. Non-return positive-closing check valves are being prescribed in all extraction lines, except for the lowest pressure heater, and two in-series valves in the deaerating heater line are recommended because of the large storage potential. The positive closing device is actuated by the turbine trip system for secondary protection.

Response rate of speed governors has improved

The ability of the turbine control system to hold the overspeed under the trip-out level, usually 10 percent, after an electrical load dump, is a function of the rotational inertia and steam energy input rate of the unit, as well as the response rate of the speed-regulating elements. The speed-governor response rate and sensitivity have been considerably improved by the use of low-inertia elements and frictionless guides at the moving parts.

Large mechanism masses and volumes of oil moved, which are inherent in the design of powerful valve operators or servomotors, account for a good share of the response time loss in the speed-governing system. The compact supercharged generator has further lowered the combined rotor inertia of the unit to such a value that the response rate of the speed governing system is no longer, in many cases, adequate to hold the turbine-generator unit under the trip-out speed following a rapid dump of full-capability load.

The use of "anticipators" or inertia governor devices to quickly close the steam admission valves after load dump and hold unit speed under trip-out level, is now becoming mandatory for installations not having an independent source of power for auxiliary equipment operation. Fig-



TYPICAL TANDEM UNIT'S overspeed and trip-out control system includes interlocked electrical anticipator. (**FIGURE 1**)

Delivery Year	Load Dump Megawatts	Rpm	Initial Accel'n Factor, $\frac{MW}{WR^2} \times 1000$	Acceleration Rpm Per Sec.	Time to Trip (All Valves Open) Seconds
Tandem Units					
1931	115	1800	0.106	127	1.42
1935	80	1800	0.096	115	1.56
1950	80	1800	0.080	95	1.88
1954	75	3600	0.518	312	1.15
1955	100	3600	0.570	343	1.05
1956	75	3600	0.567	341	1.06
1957	100	3600	0.552	332	1.08
1957	150	3600	0.613	369	0.98
1958	75	3600	0.394	237	1.52
1958	75	3600	0.518	311	1.16
1958	150	3600	0.562	338	1.06
1959	100	3600	0.552	332	1.08
1959	220	3600	0.600	360	1.00
Cross-Compound Units				**@ 3600 Turbine**	
1953	120	3600/1800	0.290	175	2.06
1954	165	3600/1800	0.347	209	1.72
1957	300	3600/1800	0.414	249	1.45
1959	250	3600/1800	0.363	218	1.65

ACCELERATION CHARACTERISTICS following a rated load dump are given for a variety of turbine units. (**TABLE I**)

ure 1 is a block diagram of a turbine-generator control system with "anticipator" governor action.

The acceleration rates of various typical reheat tandem units are tabulated chronologically in Table I. These rates are determined by assuming that the capability power output of the unit is available for conversion to kinetic energy, that is, to accelerate its rotating elements. The acceleration is evaluated by the equation,

$$\alpha = 2.165 \times 10^6 \frac{Kw}{WR^2N_1}$$

$\alpha =$ acceleration, rpm per sec.

$Kw =$ output of unit.

This acceleration occurs during the initial period following an instantaneous full-load dump, which usually results from an electrical-system-fault control relay action.

Table I, which also tabulates the acceleration rates of cross-compound units, shows that their load-dump speed-increase rates permit control of trip-out by the normal governing system. The cross-compound unit's approximate time of 1.6 seconds to reach tripping speed with all valves wide open after a load dump, allows enough time margin for the speed-governing elements to function, provided regulation is normal and stored steam is not excessive.

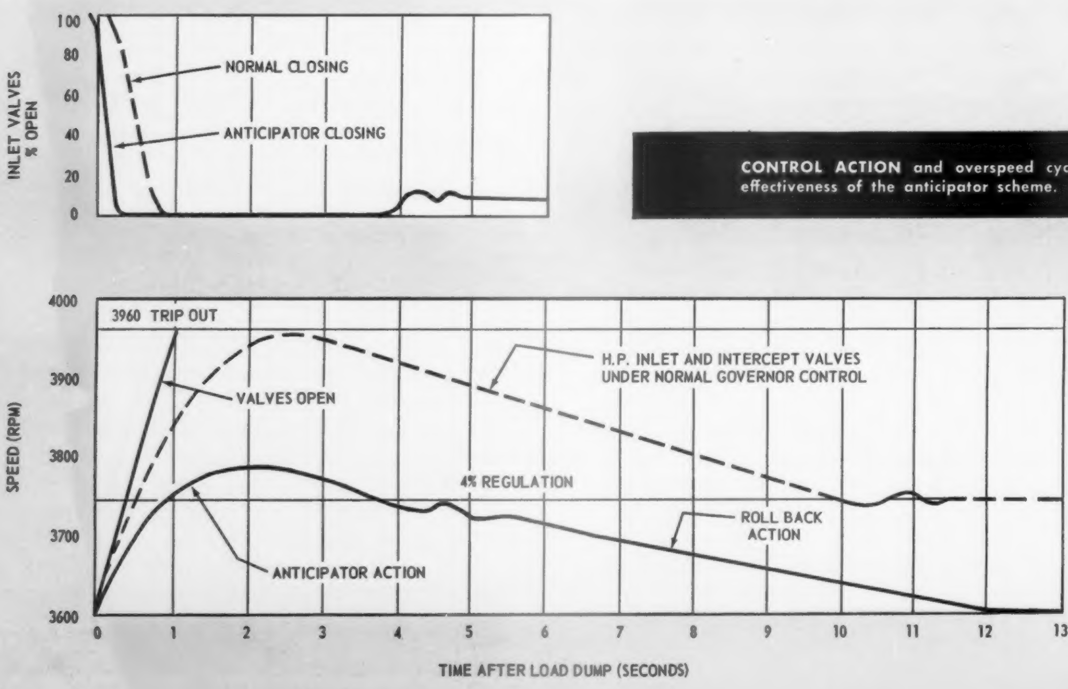
Experience has shown that when the time to reach tripping speed with all valves wide open is one second or less, special provisions are required to avoid tripping out after a full-load dump. Figure 2 illustrates the action of the inlet admission governing valves and the reheat steam control valves, as well as the turbine overspeed pattern during the first few seconds following a typical instantaneous capability-load dump of a tandem unit. The acceleration rate and control response of the typical unit illustrated makes it possible to hold the overspeed level under the trip-out speed without the assistance of anticipator devices. Many of the larger 3600-rpm reheat tandem units cannot be held below tripping speed by normal governor controls, and they require the assistance of some type of load dump "anticipation" devices.

Anticipator devices operate independently

An anticipator device does not truly sense the electrical load dump prior to its occurrence. However, the anticipator system does anticipate the necessity for fast governor control action in conjunction with relay or circuit breaker operation following the electrical fault. The anticipator system is an independent safety device which augments the usual speed-governor controls. The inertia governor, shown in Figure 3, serves a similar purpose. It is gear-driven from the turbine spindle, and its design enables it to respond quickly to the first abnormally large accelerating force tending to speed up the rotating elements of the unit. The inertia governor incorporates metering ports which immediately drop the control oil pressure to close the main inlet governing valves and the reheat steam control valves, in advance of the normal speed-governing action. This device has been used in low-inertia machines as early as 1941. The inertia governor is an effective means of preventing excessive overspeed; however, some speed change of the unit is necessary before it can function.

An electrical anticipator system, now being incorporated on turbine-generator units, is based on an electrical system relay or circuit breaker action initiating the rapid closing of the steam inlet valves. This system is being favored as a method of overspeed control. The electrical anticipator consists of additional limit switches at the relays or circuit breakers. These switches are actuated by the mechanical movements that produce the load dump on the generator.

The switches in turn energize solenoids at the governor inlet-valve load-limit device and the reheat steam intercept valves. These solenoids, by actuating oil relays, produce immediate closing of the steam control valves. The electrical anticipator system also initiates a "roll-back" feature



CONTROL ACTION and overspeed cycle illustrate effectiveness of the anticipator scheme. (FIGURE 2)

to return the turbine-generator unit to synchronous steady-state speed. This device is set in motion through a control center following the closing of the intercept valves. The "roll-back" action serves two purposes:

(1) Minimizes the time that the reheat safety valves must blow by quickly closing the high pressure inlet valves and reopening the intercepts.

(2) Minimizes the time to re-synchronize the unit and return to service.

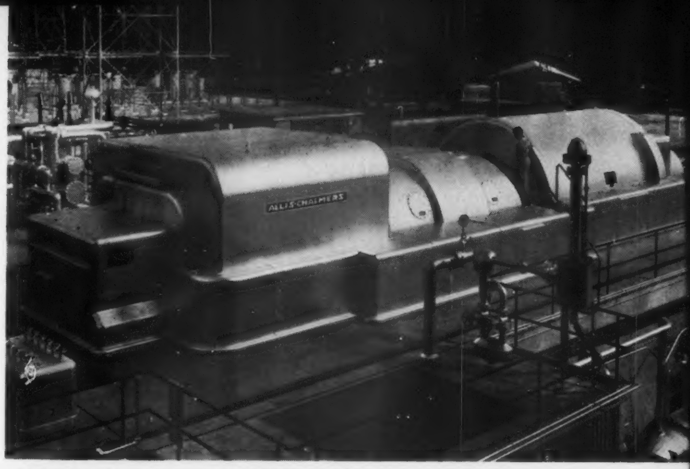
The sequence of the electrical anticipator system functions is shown schematically in Figure 4.

The number of actuating signal sources or degree of fault sensing desired deserves much study while planning the anticipator system electrical layout. The degree of protection against all possible electrical faults and the necessary telemetering and installation complications must be weighed against the consequences of a trip-out of the turbine-generator unit and boilers because of overspeed. Figure 5 illustrates an elementary block diagram of a typical system study.

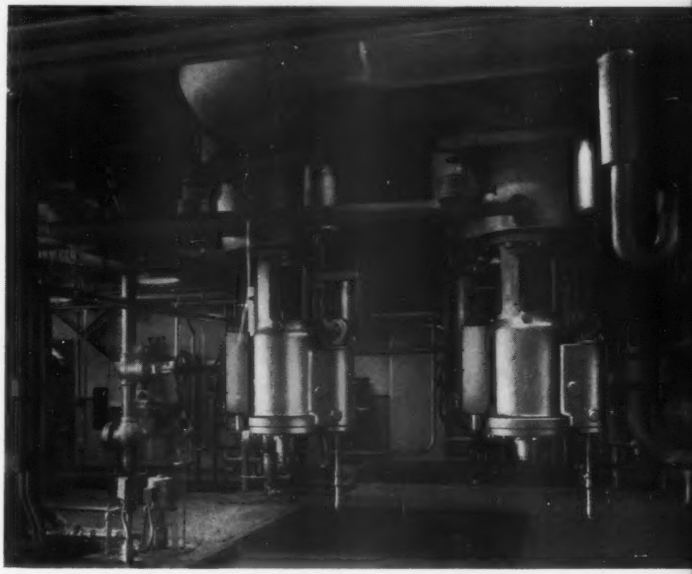
Slow acceleration is caused by seal leakage

In conjunction with a large electrical load dump, the anticipator and subsequent speed-governor action closes the intercepts and inlet valves, leaving the reheat system and the high pressure section of the turbine pressurized at high energy levels.

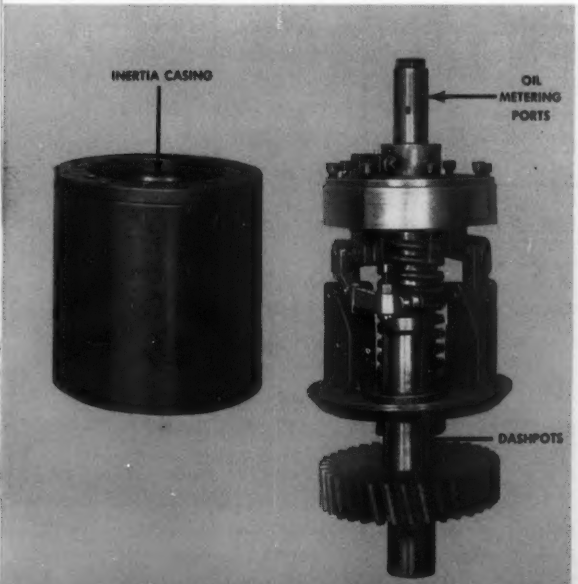
The "roll-back" action assists the rapid decay of this pressure level. During this period, however, enough steam could leak past the balance piston and reheat diaphragm seals to accelerate the unit to a possible trip-out level. This possibility is eliminated by the use of diaphragm-seal "unloading" valves which are set into action by the intercept-control oil signal from an oil-to-air relay. The seal leakage is bypassed into the condenser by means of suitable interconnecting piping. This unloading system is illustrated in Figure 6.



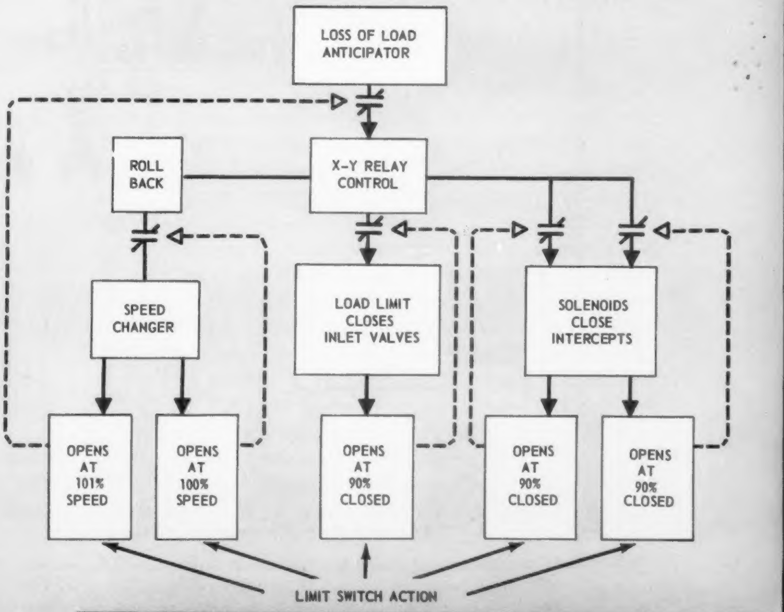
REHEAT tandem-compound, 62,500-kw turbine has rotor-supercharged hydrogen-cooled generator. Steam valves are sheltered below the deck.



REHEAT CONTROL VALVES are located close to the hot reheat inlet for maximum effectiveness in above outdoor installation.



INERTIA GOVERNOR senses initial acceleration of turbine-generator after a sudden load dump. (FIG. 3)



OPERATIONAL SEQUENCE of control components in anticipator system is shown in simplified block diagram. **(FIGURE 4)**

Overspeed controls are adequate

Present overspeed controls are adequate for today's turbines. If the capability to WR^2 ratios continue to increase, further design refinements may be necessary. A study of these ratio trends indicates further narrowing of the tripout time margin.

Other types of anticipating devices warrant investigation and development and are now under consideration. One of these devices is a synchronous permanent-magnet generator coupled with a resonant circuit and capacitance-type actuator which would serve as a sensitive speed-change-sensing device. Another system is a rapid load-change senser at the wattmeter. It is interlocked with the turbine speed changer, to close the steam control valves by means of a solenoid for rapid load changes if the unit is carrying more than 50 percent of capability rating.

Anticipatory actuating control devices will become even more important for maintaining the future power station in operation with a minimum of operating personnel.

A variety of control schemes are available to cope with overspeed and trip-out of future 3600-rpm turbines even though the capability to WR^2 ratio may increase considerably beyond present designs.

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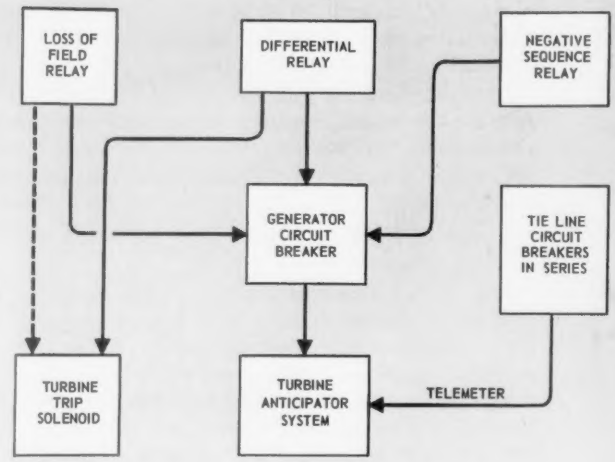
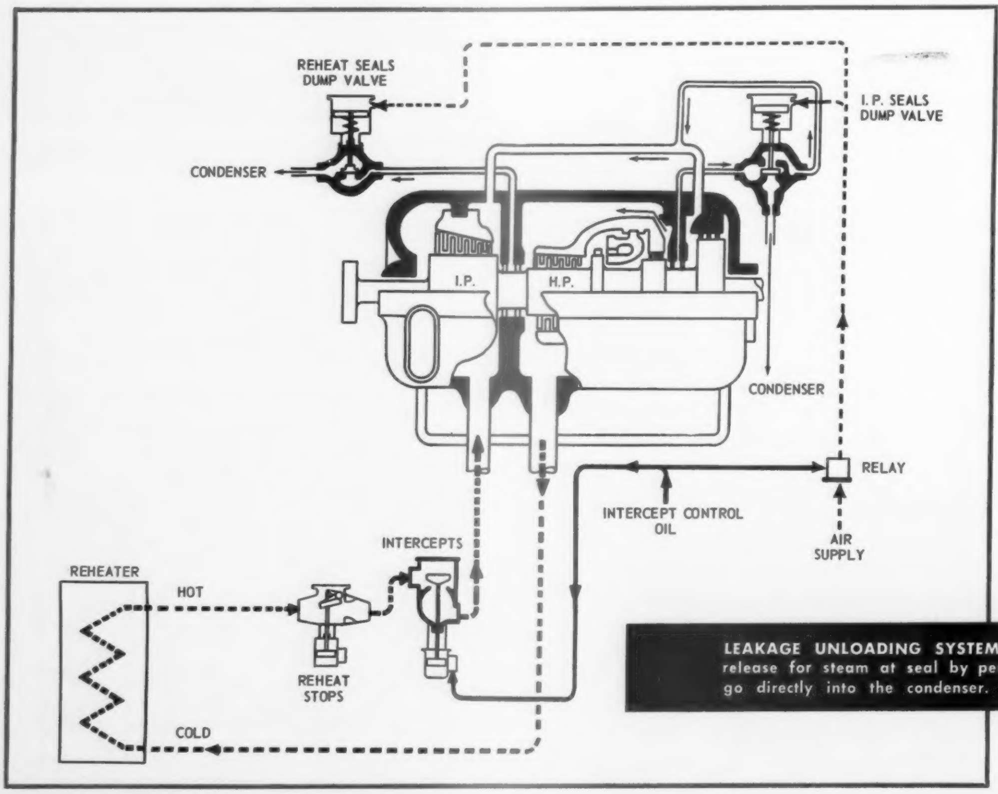
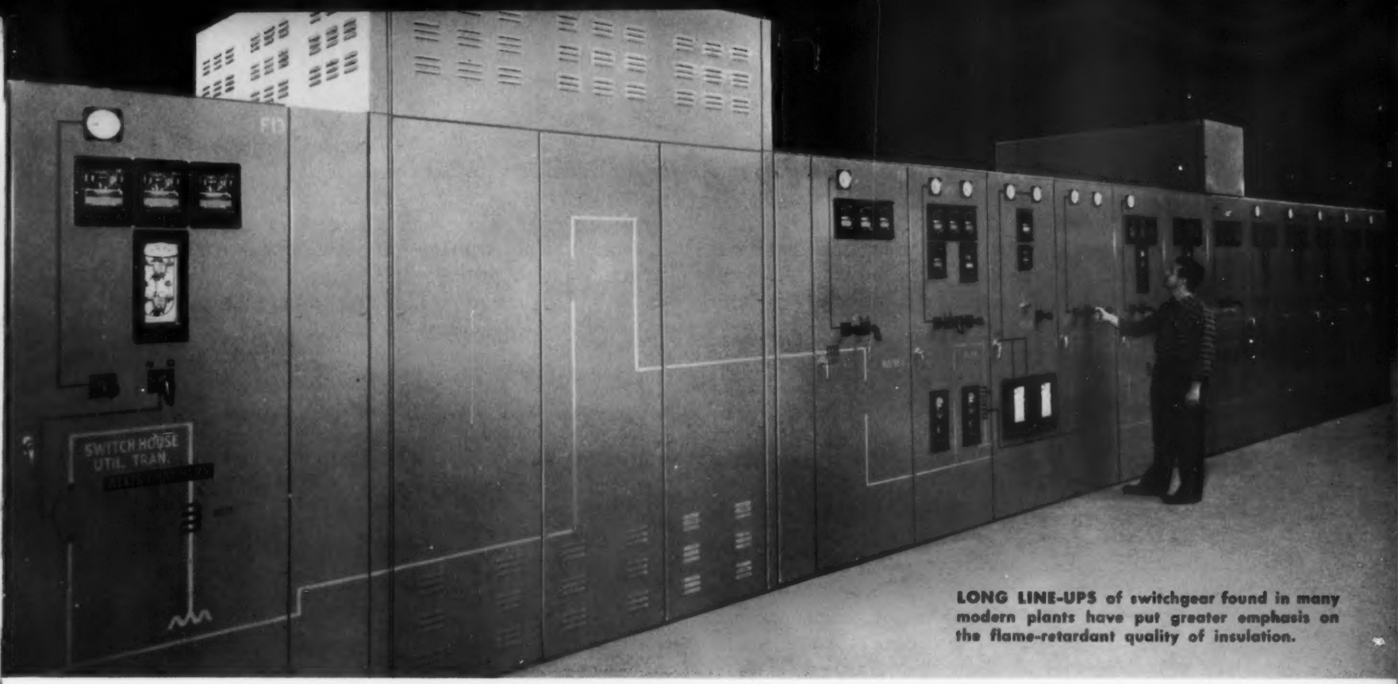


ELECTRICAL SYSTEM fault protection scheme involves both the turbine trip solenoid and the anticipator system. (FIGURE 5)



LEAKAGE UNLOADING SYSTEM provides a release for steam at seal by permitting it to go directly into the condenser. (FIGURE 6)



LONG LINE-UPS of switchgear found in many modern plants have put greater emphasis on the flame-retardant quality of insulation.

FLAMEPROOFING SWITCHGEAR

by J. H. MICHAEL
Switchgear Department
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Of the variety of new flame-retardant insulations, a number are especially valuable in switchgear.

RECENT DEVELOPMENTS in insulation materials have inspired switchgear engineers to make further advances in the reduction of fire hazards. Occasionally, in the past, serious fires in and around switchgear equipment have developed from various causes. New switchgear designs include precautions against fires spreading from unit to unit along the insulated conductors and their supports.

Some of the causes of fires are:

1. Accidental grounding of live parts by foreign objects.
2. Overheating due to forced or inadvertent overloading.
3. Exposure of the equipment to severe moisture conditions or to excessively dusty atmospheres.
4. Growth of system capacity over and above the maximum interrupting capacity of the equipment.
5. Malfunctioning of the equipment caused by mechanical failure or because of other reasons.

Switchgear engineers have been designing their equipment with these possibilities in mind since the first open-cell type gear was introduced. Metal-clad switchgear, introduced in this country in 1925, provided the first fully compartmentized switchgear equipment. In this gear all conductors were embedded in insulating compound. Since this type was offered for greater protection against fire hazards, compared to the open-cell type or truck type of switchgear commonly used at that time, it received immediate recognition from utilities, industrial plants, and especially from oil refineries where fire is a serious hazard.

The next important step along this phase of switchgear development work was the improvement in the arc suppressing devices. Up to the early thirties, all oil circuit breakers were of the plain-break variety which permitted a long arcing time prior to circuit interruption. The pressure-pot type of interrupting devices developed about this time greatly shortened the arcing period, making the oil circuit breaker a much safer and more reliable device for interrupting short circuits.

This development was later followed by the introduction of oilless circuit breakers. The possibility of fire spreading in case of an explosion in the breaker was thus eliminated.

New approach introduced

A new approach to further reduce the fire hazard in switchgear was taken in the early fifties. With the solution of other problems involving fire, the flammability of insulating materials used in switchgear to support conductors and to insulate them from each other and from ground became of greater concern. Flame-resistant ceramic insulating materials such as porcelain have been used in switchgear for many years. Although such materials have good electrical properties, their impact strength is low, and their fabrication to close tolerances is difficult. For these reasons their use in switchgear has not become extensive. On the other hand, organic materials such as paper-base phenolics have been extensively used because of the ease of their fabrication, and because their electrical and mechanical properties are generally good. Varnished cloth is another organic material which has found wide use as insulation for taping bus joints, solenoid coils, and other electrical devices used in switchgear.

Since these materials are not flame retardant, it was nec-

essary to find suitable substitutes or to modify available materials. A material is said to be flame retardant if, when subjected to an arc or to any other flame source, it will burn while under the influence of the external flame, but it causes its flame to extinguish as soon as the external flame is removed. Flame resistant insulation will not burn but may be damaged mechanically by the heat.

After considerable experimentation, manufacturers of phenolic insulating materials succeeded in producing grade "X" and grade "XX" flame-retardant phenolic laminates by adding certain ingredients to their raw materials. Other manufacturers have produced new solid insulating materials that are also flame retardant, such as glass-base polyester laminates. Flame-retardant tape insulation such as polyvinyl chloride was also made available.

Tables I and II list some of the most common types of flameproof or flame-retardant insulations one may encounter in switchgear equipment today. Table I covers some of the ceramic type of insulating materials, all of which are flameproof or flame resistant, and Table II covers a number of plastic insulating materials which are more or less flame retardant. Grades "X" F.R. and "XX" F.R. are relatively new, while others have been on the market for some time.

It is regrettable that no one insulating material has been discovered which possesses all the desirable mechanical and electrical characteristics, resists flame and the effects of temperature variations, stands up well under severe humid conditions, and is economical to produce and to fabricate. Switchgear designers are therefore forced to select and specify the best insulating materials for the application. The properties of these various insulating materials are discussed below.

Ceramic insulation is limited in application

Ceramic materials are flame resistant, have good insulating properties and are low in moisture absorption. However, their impact strength and tensile strength are generally low, and consequently these materials cannot be considered where impact stresses or high tensile stresses are involved. Also, the machinability of ceramics is generally difficult and expensive, thereby limiting their use to applications where close tolerances are not essential. Since the surface of ceramic insulating materials is generally non-tracking, occasional intermittent surface discharges, due to dirt or moisture, do not tend to form low resistance paths for power arcs to follow. For this reason, glass and porcelain are used in various forms for bushings and other insulating components in switchgear. Zircon is mostly used in arc chutes because of its high thermal impact strength.

Glass-bonded mica, which is a ceramo-plastic, resists flame and has excellent electrical properties and fairly good mechanical properties. It is not free-machining, however, and is comparatively expensive; for these reasons its use for switchgear insulation is limited.

Dielectric strength of plastic insulation varies

Table II lists several plastic insulating materials which are more or less flame retardant. Of these materials, resin-bonded asbestos paper, grade "A," and resin-bonded woven asbestos fiber, grade "AA," have lower dielectric properties than other types of laminates. Since NEMA standards do not recommend these materials for primary insulation, their usage is also limited.

From the standpoint of flame retardancy, the melamine resin-bonded glass fabric, grade G-5, and silicone resin-bonded glass fabric, grade G-7, are the best. Although their dielectric and mechanical properties are good, both G-5 and G-7 are expensive. Grade G-5 costs slightly more than twice as much as "XX," while G-7 costs roughly about six times as much as "XX," pound for pound. Volume for volume, this price differential is higher because the specific gravity of G-5 and G-7 is higher. Both these materials are difficult to fabricate, and furthermore G-5 absorbs sufficient moisture in humid atmospheres to lower its dielectric properties considerably. For the above reasons, these glass-fabric base, thermosetting laminates find little use, if any, in switchgear.

Grade "XX" F.R. material is the regular "XX" paper-base phenolic except that additives make it flame retardant. Similarly, grade "X" F.R. is the same as the regular "X" grade paper-base phenolic, but it also has flame-retardant additives. Both "XX" F.R. and "X" F.R. are recent developments and cost slightly more

TABLE I. PROPERTIES OF SOME CERAMIC AND CERAMO-PLASTIC INSULATING MATERIALS

				Mechanical Characteristics				Electrical Characteristics						
										Power Factor				
Type of Material	Trade Name	Water Absorption	Specific Gravity	Compressive Strength (psi)	Tensile Strength (psi)	Modulus of Rupture (psi)	Impact Strength (ft lb/sq in.)	Dielectric Strength V/M (0.2" thk.)	Dielectric Constant 1 megacycle	60 Cycle	1 Megacycle	Volume Resistivity (ohm/cm cu)	Te[1] (C)	Approximate Maximum Working Temperature[2] (C)
Ceramic	Electrical Porcelain (High Voltage)	0.000 to 0.030	2.3 to 2.5	40,000 to 80,000	6,000 to 8,000	10,000 to 18,000	1.5	250 to 300	5.5 to 7.0	0.067	0.006 to 0.01	10^{10} to 10^{14}	280 to 300	1000
	Electrical Glass (Lead Type)	nil	4.3	50,000 to 180,000	2,000 to 4,000	7,000 to 18,000	. . .	340	7.0 to 9.0	0.08	0.0009	10^{17}	400	180
	Electrical Glass (Borosilicate)	nil	2.3	50,000 to 180,000	2,000 to 4,000	7,000 to 18,000	. . .	340	4.0 to 4.5	. . . . .	0.0002 to 0.002	10^{16} to 10^{18}	700 to 900	250
	Zircon	0.000 to 0.05	3.0 to 3.8	70,000 to 150,000	10,000 to 15,000	20,000 to 30,000	2.1	225 to 300	7.0 to 9.0	0.015 to 0.03	0.001 to 0.008	10^{13} to 10^{15}	700	1000
Ceramo-Plastic	Glass-Bonded Mica	nil	2.6 to 3.8	27,000 to 35,000	5,000 to 7,000	12,000 to 15,000	1.2 to 3.5	300 to 400	7.0 to 9.0	0.02	0.0015 to 0.003	10^{12} to 10^{15}	300	300

[1] *Te* is the temperature at which the volume resistivity equals 10^6 ohms/cm cu.
[2] For mechanical considerations only.

TABLE II — PROPERTIES OF SOME FLAME-RETARDANT PLASTIC INSULATING MATERIALS

Type of Plastic	NEMA Grade or Trade Name	% Water Absorb. 1/16" thk. D-24/23	Specific Gravity Condition A	Mech. Characteristics—Cond. A: Tensile Strength (psi)	Mech. Characteristics—Cond. A, Flatwise: Compressive Strength (psi)	Mech. Characteristics—Cond. A, Flatwise: Flex. Strength (psi)	Mech. Characteristics—Cond. A, Flatwise: Impact Strength (ft lb/in. notch)*	Electrical Characteristics, Diel. Strength Condition A: Perpend. to Lam. V/M	Electrical Characteristics, Diel. Strength Condition A: Parallel to Lam. (kv/in.)	Electrical Characteristics, Dielectric Constant: Cond. A 1 megacycle	Electrical Characteristics, Dielectric Constant: Cond. D-24/23 1 megacycle	Electrical Characteristics, Power Factor Condition A: 60 Cycle	Electrical Characteristics, Power Factor Condition A: 1 megacycle	Insulation Resistance Meg. —Condition C96/35/90	Arc Resistance Seconds	Flame-Retardance Index "F"	Possible Maximum Continuous Temperature (C)
Thermosetting Laminates	Asbestos Grade A	1.3 to 1.5	1.7	8,000 to 10,000	38,000 to 40,000	16,000 to 34,000	1.8 to 3.5	225 to 265	10 to 11	7.0	7.3	......	0.185	....	....	−0.4	135
	Asbestos Grade AA	1.5 to 3.0	1.7	10,000 to 12,000	38,000 to 39,000	16,000 to 21,000	3.0 to 4.8	78	10	7.5	12.5	......	0.736	....	....	−0.3	135
	Grade G-3	2.2 to 2.7	1.7	20,000 to 28,000	39,000 to 55,000	18,000 to 32,000	6.0 to 12.2	500 to 700	45 to 52	4.8 to 5.5	5.1 to 5.5	......	0.015 to 0.030	....	....	+0.8	140
	Grade G-5	2.7 to 3.4	1.9	30,000 to 29,000	54,000 to 70,000	35,000 to 65,000	12.0 to 20.0	350 to 600	30 to 35	6.1 to 7.8	6.7 to 7.9	......	0.011 to 0.020	100	180 to 200	+6.0	150
	Grade G-7	0.3	1.7	17,000 to 28,000	35,000 to 75,000	18,000 to 44,000	6.0 to 10.0	250 to 430	45 to 55	3.2 to 4.0	3.3 to 4.4	0.003	0.0015 to 0.002	2,500	220 to 240	+5.5	200 to 250
	Grade "XX" F.R.	0.8 to 1.2	1.4	8,000 to 11,000	30,000 to 40,000	13,000 to 20,000	1.5 to 3.0	500 to 750	58 to 89	5.6 to 6.1	6.2 to 6.5	0.030 to 0.500	0.034 to 0.050	700,000	70 to 122	+2.2 to +4.9	120
	Grade "X" F.R.	1.7 to 3.0	1.4	10,000 to 20,000	30,000 to 40,000	19,000 to 25,000	2.4 to 3.8	300 to 500	45 to 70	5.0 to 7.2	6.0	0.074 to 0.155	0.03	....	70 to 80	+3.15	107
	Grade GPO	0.2 to 1.0	1.9	12,000 to 15,000	30,000 to 40,000	23,000 to 35,000	10.0 to 14.0	360 to 400	50 to 60	4.5	4.8	0.011 to 0.040	0.015 to 0.044	5,000	120 to 180	+2.7 to +3.7	125
Thermo-Plastic	Neoprene	** 0.53	1.6	1,800 to 2,500	....	....	.....	200 to 350	....	7.0 to 8.0	....	......	0.012	100	....	+3.1 to +4.3	100
	PVC	0.4 to 0.75	1.35	1,400 to 3,000	....	....	Rigid Type 0.4 to 0.7	300 to 400	....	3.0 to 8.0	....	0.03 to 0.20	0.045 to 0.065	2,000	....	......	80 to 105

NOTES:

1. Dielectric strength is "short time" strength of 1/16 inch thick material except for Neoprene, which is for 1/8 inch thick material.
2. Condition "A" implies material as received.
3. Condition D-24/23 implies material is soaked 24 hours in water at 23 C.
4. Condition C96/35/90 implies that the material was conditioned 96 hours at 35 C and 90% relative humidity.
5. Flame retardance index "F" (as suggested at present) has a value equal to $10\left(\frac{I-B}{I+B}\right)$, where I = ignition time in seconds and B = burning time in seconds as determined by LP406b—Method 2023.1.

*Per ASTM Standard D-256.

**On 1/8 inch thick materials.

than the regular "X" and "XX." Because the electrical characteristics of the "XX" F.R. closely approximate those of the regular "XX," this flame-retardant material is now extensively used for switchgear insulation. Grade "X" F.R. is also used in switchgear where dielectric stresses are low enough to permit its use. Both "XX" F.R. and "X" F.R. usually come in red to distinguish them from the regular "XX" and "X" grades, which usually are left natural or are colored black.

Glass-mat polyester, grade "GPO," is another flame-retardant thermosetting laminate which has recently received recognition as switchgear insulating material. It has electrical properties approximately equal to those of "XX," and mechanical properties better than those of "XX." Grade "GPO" has low moisture absorption and its 60-cycle power factor, up to the maximum working temperatures encountered in switchgear, does not vary as widely as that of the paper-base phenolics.

Thermoplastic insulations find varied uses

The thermoplastics Neoprene and PVC (polyvinyl chloride) are widely used as insulation on wires and cables in switchgear equipment. Neoprene is also used as insulating material in the form of boots over bus-bar joints. Compounds of PVC are applied as insulating coatings on coils and on some low voltage switchgear conductors. PVC insulation is also used in tape form.

Other types of electrical insulating materials may be encountered in present-day switchgear, some of which may or may not be flame resistant or flame retardant, but those described above are most common.

Research and development work toward reducing fire hazards in switchgear equipment is still going on. Encapsulation of various switchgear devices in flame-retardant resins is now being investigated, and various other phases of the problem are being considered. The results of these investigations look promising.

FLAME-RETARDANT insulation on switchgear bus prevents fire from following along the bus from unit to unit in new 15-kv gear.

Testing Flame-Retardant Quality of Insulation

BURNING TIMES for various insulation samples can be compared or duplicated when conditions are carefully controlled. (FIG. 1)

by R. H. LAMBERT
Switchgear Department
Allis-Chalmers Mfg. Co.

Comparing and evaluating new flame-retardant insulations are important functions in switchgear development work.

TO SPEED UP the adoption of improved insulation materials, switchgear engineers have developed a new test device to help them evaluate the flame-retardant quality of various insulating materials.

Flame retardance is produced through the use of additives, such as borax, boric acid, aluminum sulphate, ammonium sulphate, hydrated sodium carbonate, calcium chloride, and polyvinyl chloride. With the great number of additives available and with the many different formulations of phenolic materials now in use, evaluating the effectiveness of their flame-retardant qualities requires careful testing and analysis of the test results.

The American Society of Testing Materials has three basic testing standards which can be applied to flame-retardant or fire-resistant materials:

1. ASTM-D568-43 for plastics under 0.050 inch thick, utilizing the benzol drop test.
2. ASTM-D635-44 for plastics over 0.050 inch thick, using a Bunsen burner.
3. ASTM-D757-49 for self-extinguishing plastics, using a globar element.

TABLE 1. TABULATION OF TEST DATA ON FLAME-RETARDANT PHENOLIC MATERIALS

Supplier	Sample No.	Original Weight	Final Weight	Weight Loss	Weight Loss Average	Ignition Time (sec.)	Average	Burning Time (sec.)
A	1	76.71	67.97	8.74	9.45	167.4	185.58	153.6
	2	76.88	66.85	10.03		200.8		156.2
	3	75.19	65.96	9.23		180.2		156.7
	4	78.83	69.02	9.81		193.9		149.32
B	7	76.06	72.48	3.58	6.00	163.0	245.25	23.8
	8	77.06	68.44	8.62		359.7		45.5
	9	77.89	73.89	4.00		181.7		18.7
	10	71.78	64.00	7.78		276.6		64.2
C	13	77.23	73.98	3.25	3.08	91.3	81.63	53.6
	14	78.12	.....	.....		80.4		49.9
	15	74.05	70.73	3.32		81.6		50.7
	16	75.83	73.16	2.67		73.2		50.2
D	19	73.70	70.67	3.03	2.61	90.8	87.33	38.6
	20	73.24	71.74	1.50		73.8		27.2
	22	75.56	72.64	2.92		90.1		46.1
	23	75.42	72.44	2.98		94.6		35.9
E	25	71.88	67.15	4.73	4.00	124.3	110.08	37.0
	26	74.59	69.57	5.02		125.2		40.6
	27	73.78	69.36	4.42		117.4		37.2
	28	73.25	71.42	1.83		73.4		38.3
F	30	75.70	70.75	4.95	4.81	102.5	105.75	64.9
	31	76.93	72.40	4.53		101.6		66.2
	32	75.39	70.07	5.32		112.9		71.5
	33	76.29	71.86	4.43		106.0		71.0
G	43	73.60	69.92	3.68	3.53	83.8	81.28	43.9
	44	76.99	73.44	3.55		81.2		50.3
	48	77.67	74.35	3.32		78.2		44.4
	49	78.20	74.62	3.58		81.9		44.6

All samples conditioned for 24 hours at 25 C and 50% R.H. before testing.

Better results obtained with new method

Investigations showed that test methods 2 and 3 were not sufficiently consistent to permit conclusive comparison of materials. In order to obtain more accurate results, a new method was devised, based on a test method used by the U.S. Navy and the U.S. Bureau of Mines.

A new test device, shown in Figure 1, provides consistent results because both the amount of heat and the volume of air flow are controlled. Figure 2 shows the setup for a given sample.

A resistance-type heating coil is centered over the chuck holding the insulation sample. On either side and directly above the coil are movable gas ignition electrodes. Timers control the ignition period, the interim period and the burning period. After the ignition period, heating is continued for 30 seconds and then turned off. Burning time is recorded from this instant. When the sample has extinguished its flame, the burning period is complete.

The test machine is carefully calibrated so that results can be repeated consistently and the calibration of one machine can be compared with that of another machine.

Although material performance is not consistent from one testing machine to another, it is relatively easy to compare different materials on any one machine. To measure or compare materials, a ratio of burning time to ignition time is used. The lower the ratio, the greater the flame-retardance. Table I is an example of a tabulation of different materials, four samples of each being used. Slight differences in results are caused by non-homogeneity of the material.

During testing it was found that a given size sample may appear to change its designation from flame retardant to non-flame retardant. This effect was due to size variation in relation to the proximity of the sample surface to the coil and the heat absorption for the particular cross-section. For example, a large sample would ignite quickly, but extinguish immediately; a smaller size sample would ignite slowly, but burn completely. Since a larger-sized sample is closer to the heating coil, it will absorb more heat in a given time period and thus burn more readily.

CAREFUL POSITIONING of sample in heating coil assures consistent results. The ignition electrodes are shown tilted out of position while the sample is being clamped in place. **(FIG. 2)**

In view of the wide range of results obtained because of variation in sample size and differences in calibration between different machines, a standard definition of flame retardance and a standardized method of testing are necessary for uniformity of specifications and data. Insulation manufacturers are working to obtain this standardization. With the establishment of a definition and a standard means of testing flame retardance, insulation manufacturers, equipment builders, and ultimate users will be able to determine, specify or test for this important insulation characteristic more accurately.

TABLE 1 (CONT.). TABULATION OF TEST DATA ON FLAME-RETARDANT PHENOLIC MATERIALS

Supplier	Sample No.	Average	Flame Height (Inches)	% Burn to Ignition Time	Smoke	Remarks
A	1 2 3 4	153.95	5+ 4+ 5+ 5+	83.0	Med. to dense gray	Sample broke up on cooling
B	7 8 9 10	38.05	3+ 4+ 3+ 5+	15.5	Gray to light black	
C	13 14 15 16	51.10	3+ 4+ 5 4	62.5	Gray to light black	Sample spread to coil on burning
D	19 20 22 23	36.95	3+ 2 4 5	42.3	Light gray	
E	25 26 27 28	38.28	5 5+ 5+ 3	34.8	Med. gray and sooty	
F	30 31 32 33	68.40	5+ 5+ 5+ 5+	64.8	Light gray	Sample spread to coil on burning
G	43 44 48 49	45.80	5+ 5+ 5 5	56.3	Light gray and black	

All samples conditioned for 24 hours at 25 C and 50% R. H. before testing.

COLOSSAL ST. LAWRENCE POWER DAM stretches for 3300 feet across the north channel of the mighty St. Lawrence River from American Barnhart Island to the Canadian shore. Here 32 propeller type hydraulic turbines, now being installed, will produce nearly 2½ million horsepower by 1959. This night view shows some of the American side units during the 1957 construction stage when the parts were being grouted in and the lower halves of their concrete scroll cases were still visible. One of the turbine runners is shown on the front cover.

RELIEVE YOUR ENGINEER SHORTAGE...

discover more time for engineering

by **G. E. FELDMAN**
Wage Administration and Research Section
Allis-Chalmers Mfg. Co.

AN ENGINEER'S professional background helps him to evaluate multiple use of intricate parts. New products are the result of his creative ingenuity. **(FIGURE 1)**

Work sampling will help today's engineer shortage by channeling routine work to technicians and other specialists.

THE CURRENT SHORTAGE OF ENGINEERS has excited great interest, since there is little doubt that the nation's engineering schools are supplying engineers in numbers less than industry demands. Each major new invention, while solving an immediate problem, will open up whole new areas for scientific and engineering developments requiring more and more engineers.

Through better use of engineering talent, the current shortage can be reduced and the individual engineer becomes more valuable. Work normally performed by an engineer which requires less than a professional engineering background possibly could be assigned to technicians and clerical personnel, giving the engineer more time for professional activity, as shown in Figure 1.

Technicians can relieve engineer shortage

Engineers themselves realize that if they were relieved of much routine they would be able to devote more time to real engineering. Some engineers might increase their usefulness by being free to develop their skill and talent without unnecessary hindrance. A project is sometimes delayed because the engineer may not have enough time to give it the attention it deserves.

Estimates by other writers on this subject indicate that the average engineer might spend from 10 to 30 percent of his time doing work at a professional engineering level. The remaining time, they infer, is spent on work which could be performed by clerks or specialized technical assistants. If engineers could devote 60 to 80 percent of their time to real engineering work instead of the present suggested 10 to 30 percent, the effect could multiply an engineering staff from 2 to 8 times by hiring clerks, typists, and technicians. While this seems to be somewhat exaggerated, certainly it is worth looking into and considering possible improvements.

The solution sounds good, but it leaves a seemingly insurmountable problem — how do engineers spend their time? A technique which has been popularized under the term "work sampling" presents very interesting possibilities whenever one is faced with a problem of measuring human activities. Figure 2 shows a group of typical situations in which an engineer finds himself during his day.

A time-study method might be used to evaluate an engineer's time, but this method has some disadvantages. Time studies are intended primarily for an operator working on a production machine. Engineering activity does not readily lend itself to time study, since an engineer does not work in a definite pattern involving a series of motions. A time-study breakdown will probably be inaccurate because no one is immune from the effect of an observer, and the observer may not be well enough informed to make a correct evaluation. The cost of a full time study would be expensive and also during the study an engineer might have problems that are not typical.

Practical method indicates a solution

Work sampling proposes an answer to many of the problems encountered when analyzing the activities of engineers. It is fundamentally just one more application of an approach to data gathering that is very common in industry today — random sampling. This method involves taking samples out of a large number of items, at random, and makes accurate predictions about the entire lot. Pollsters sample opinions to predict reaction to a new product. Quality control inspectors take samples of parts for analysis and predict the characteristics of an entire lot. In work sampling, an observer takes sample observations of the activities of people to predict how these people use their time. For work sampling to be effective in observing an engineer's activity, it is vital that the observer be familiar with the work to forestall erroneous evaluation.

How work sampling results in better use of engineers is illustrated in a sample situation. Suppose that a three-month period were chosen as representative of an engineer's activities. That three-month period consists of 63 eight-hour work days. Applying work sampling to this situation involves observing a relatively small number of random instants in order to make a reasonable estimate of an engineer's activities during the test period. Work sampling uses a unit which is called "instantaneous observation." This could be considered as a mental snapshot of the person studied. For example, suppose that the first instantaneous observation of a particular day, Monday, August 19, was selected at random and set for 8:47 A.M. At exactly 8:47 A.M. the observer takes a mental snapshot of the engineer. At that instant he is working on the calculating machine. A mark is then made in the observer's note sheet opposite a category called "Routine Computations." The steps to make a proper instantaneous observation are:

1. Specific observation of a random instant in the period studied.

2. Classification of the observation into a category of activity.

3. Tallying the observation on the observation form.

The observer must take a sufficiently large sample in a representative period of time so that he can make a useful and accurate prediction of the future. If the three-month period were chosen for study, a large number of instantaneous observations would be spread equally among the work days included. A typical work sheet in Figure 3 shows the entries made when an observer samples the activities of one man.

A random number table in three digits (such as numbers in the range 000 to 999) could be interpreted as:

1. First digit—hour of the working day.

2. Second and third digits—minute of the hour.

Drawing the first random number from the random number table, the result might be 546. This would mean 12:46, that is, the 46th minute of the 5th hour. It would signal an instantaneous observation to be made at the instant when 12:46 is reached.

There is a simple mathematical statement which relates sample size to accuracy. This statement is:

$$T = 2\sqrt{\frac{P(100-P)}{N}}$$

where T = tolerance.

P = the percentage of a given category in the whole sample.

N = total sample size.

Sample calculation solves a typical problem

Consider a design engineer as an example. When the observer has recorded 10 observations per day for a three-month period, then N would be 630 (63 days times 10 observations per day). The observations were divided into the following categories and these are the results:

AN ENGINEER has to do many things, including some routine work which may not require full use of his abilities. Some work might be assigned to technicians, but only an observer acquainted with the nature of the work could make an effective evaluation. **(FIGURE 2)**

A.	Engineering Work (Technical research, library, society and technical reports, magazines, etc.)	204	32.4%
B.	Routine Clerical Work	31	4.9%
C.	Expediting and Solving Production Problems	112	17.8%
D.	Routine Computations, Report and Instruction Writing	213	33.8%
E.	Personal Time	52	8.2%
F.	Miscellaneous Time	18	2.9%

If the category "Routine Computations" is considered, P is equal to 33.8 percent. The formula is now solved to determine the accuracy of the results.

$$T = 2\sqrt{\frac{P(100-P)}{N}}$$

$$= 2\sqrt{\frac{33.8(66.2)}{630}}$$

$$= 3.8\%$$

The computed results show that "Routine Computations" took 33.8 ± 3.8 percent of the engineer's time during the three-month span. Similar computations would produce other specific statements about the remaining five categories considered in the study. Increased accuracy can be achieved by increasing the size of the sample used.

Simultaneous observations save time

One advantage of work sampling is the ease with which it can be used to conduct simultaneous studies. The random instant can be used as a basis for a series of observations instead of just one. If five engineers were located in close proximity to each other, the observer could glance at all five and make five separate observations for each random instant. Combined observations made on all five engineers make it possible to evaluate the group as a whole.

The work sheet used when several men are observed is shown in Figure 4. Simultaneous study has value when a supervisor wants to know how many clerks or technicians to add to an engineering section. Separate observations and analysis of each individual's use of time are comparable to five complete studies. Work sampling makes efficient use of observer's time, but interruptions to make observations are disconcerting when the observer is trying to do other work. Simultaneous observations help to pay for the intangible costs of interruption to normal work.

By using the results of the studies, supervisors or chief engineers can meet staff needs effectively. Effective action would be unlikely without using the results of the study — to make better use of engineering talent by passing less demanding work to other types of employes.

When the basic study is completed and changes put into effect, a follow-up study should be made. It need not be as long or as intensive as was the basic study to provide the necessary information. Too many excellent improvements never realize their potential because no one has checked to find out the actual results of the initial action.

The Working Committee for the Development of Supporting Technical Personnel, in reporting to President Eisenhower's Committee on Scientists and Engineers, states that modern industrial nations need to produce 200 engineers per million population per year. This means that the United States requires 35,000 engineering graduates per year. It will be some time before the necessary number of engineers becomes available to industry.

This discussion is intended to be thought-provoking. It is not a cure-all. The extra cost of technicians and clerks must be balanced against increased overall production. An engineer capable of supervising a number of non-technical assistants must have a sufficient and varied work load to be able to plan both his time and their time. All young engineers are not born supervisors. Only on repetitive problems can the technician take over without lengthy explanation and close supervision. Sometimes on a short problem it is quicker, easier and more efficient to do it yourself than to try to explain it to others. The real problem is to select the combination of brains, manpower and machines that produces the most results for the least dollars.

WORK SAMPLING PROJECT

SUBJECT STUDIED JOHN DOE — TIME PERIOD Week of Aug. 26, 1957
OBSERVER BILL JOHNSON — LENGTH OF STUDY 3 MONTHS

CATEGORY	SYMBOL	SUMMARY
Engineering Work	E	16
Routine Clerical Work	Cl	3
Expediting and Solving Prod. Problems	S	9
Routine Computations, Report and Instruction Writing	Comp	17
Personal Time	P	4
Miscellaneous Time	M	1
		50

MONDAY-26 AUG.		TUESDAY-27 AUG.		WEDNESDAY-28 AUG.		THURSDAY-29 AUG.		FRIDAY-30 AUG.	
TIME	OBS.	TIME	OBS.	TIME	OBS.	TIME	OBS.	TIME	OBS.
8:56	E	8:16	M *	8:35	COMP	8:05	E	8:21	COMP
10:04	P	8:47	E	9:43	E	8:22	COMP	9:28	S
11:19	E	9:51	S	10:24	E	9:49	S	9:54	S
1:37	CL	9:55	E	11:01	S	9:53	COMP	10:06	E
1:53	S	10:38	E	11:06	P	10:33	E	11:16	COMP
2:09	E	11:03	COMP	11:59	COMP	11:13	P	1:59	CL
3:10	S	1:36	COMP	1:17	E	1:26	E	2:32	COMP
3:27	COMP	3:10	E	1:32	S	1:56	COMP	2:43	COMP
4:25	COMP	3:29	COMP	1:41	COMP	2:55	E	3:44	S
4:36	COMP	3:40	CL	4:33	E	4:17	COMP	4:51	P

* ADJUSTING CHAIR

WORK SHEET form can be used to advantage when a qualified observer records engineering activity. Many observations are necessary to get a realistic picture of activities studied. **(FIGURE 3)**

WORK SAMPLING PROJECT

SUBJECTS STUDIED: Bill Richards, John Doe, Tom Huff, Al Garder, George Merritt, Ralph Wood, Jim Davies, Bob Czari, Earle Marter, Howard Dair

TIME PERIOD — Wednesday, 2 October 1957

OBSERVER — Bill Johnson

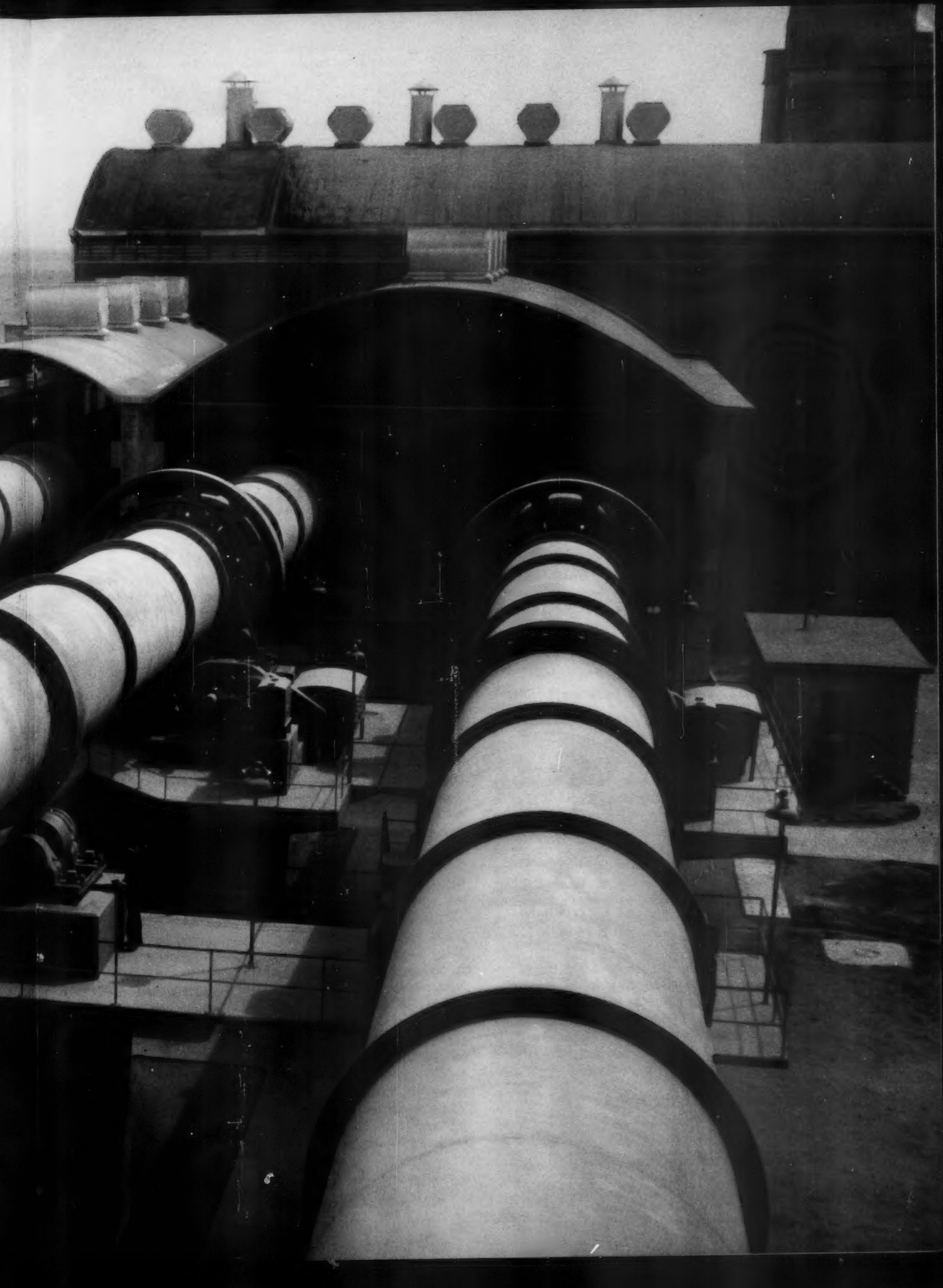
LENGTH OF STUDY — 3 Months

CATEGORY	Symbol	Bill	John	Tom	Al	Geo.	Ralph	Jim	Bob	Earle	Howard	Total
Engineering Work	E	3	4	4	4	2	3	2	3	3	2	30
Routine Clerical Work	Cl	1	1	0	0	1	1	1	0	1	0	6
Expediting and Solving Prod. Problems	XP	1	2	1	2	4	2	3	0	0	3	18
Routine Computations, Report and Instruction Writing	Comp	4	3	4	4	2	2	2	6	5	3	35
Personal Time	P	1	0	1	0	1	1	2	1	1	1	9
Miscellaneous Time	M	0	0	0	0	0	1	0	0	0	1	2
		10	10	10	10	10	10	10	10	10	10	100

Time	Bill	John	Tom	Al	Geo.	Ralph	Jim	Bob	Earle	Howard
8:32	XP	E	XP	Comp	E	XP	Comp	E	Comp	E
9:14	E	E	Comp	E	Comp	XP	E	Comp	Comp	XP
10:21	Cl	E	E	Comp	E	Cl	E	Comp	E	XP
10:59	P	Cl	P	Comp	XP	Comp	P	Comp	E	Comp
11:17	E	Comp	E	E	XP	E	Cl	Comp	E	XP
12:55	Comp	E	Comp	E	Cl	Comp	XP	E	Comp	M
1:21	E	XP	Comp	Comp	Comp	E	XP	E	Cl	E
2:16	Comp	XP	Comp	E	XP	M	XP	Comp	Comp	Comp
2:50	Comp	Comp	E	XP	XP	E	P	Comp	P	Comp
3:44	Comp	Comp	E	XP	P	P	Comp	P	Comp	P

WHEN SEVERAL ENGINEERS are working close to each other on the same or similar problems, the qualified observer can then make a simultaneous record of the activity of each man. **(FIGURE 4)**

THREE 10 BY 340-FOOT ROTARY KILNS in a Lone Star Cement Corporation plant are working to satisfy the ever-increasing needs of today's construction industry. The plant, in Maryneal, Texas, requires 190,000 kwhr for normal operation during a 24-hour day. The installation includes vibrating screens, crushers, finish and raw grinding mills, and miscellaneous auxiliary and electrical equipment.
Allis-Chalmers Staff Photo by Henry Serdy



ULTRASONIC TESTING METHOD holds the search unit against the revolving shaft. The sturdy support reduces extraneous vibration. Sonic pattern is viewed on reflectoscope screen. **(FIGURE 1)**

Ultrasonics — The Key To Locating Defects In Metal Structure

by **ROBERT N. HAFEMEISTER**
Non-Destructive Test Section
Allis-Chalmers Mfg. Co.

An ultrasonic wave introduced into a metal part produces a pattern that accurately locates any flaw in the metal.

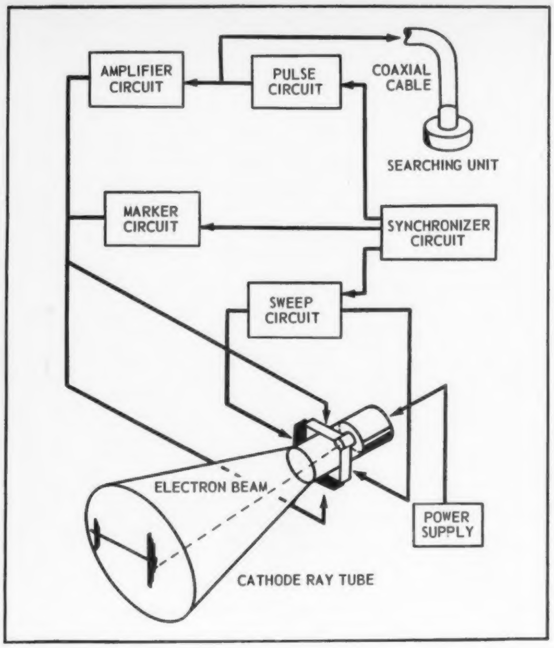
ULTRASONICS is one of the most widely used methods of non-destructive testing in industry today. Making its debut as a production tool shortly after World War II, it has in the past ten years become indispensable as a means of determining quality. Today, there are quality specifications covering the acceptance or rejection of all the major components of a steam turbine generating unit, including shafts, miscellaneous forgings, and pipe. Work is being done on castings and weldments toward issuance of working specifications. It is possible, with present techniques, to discover that a forging contains flakes, bursts, porous areas, isolated slag inclusions, or has been improperly heat-treated. Techniques are being developed which will enable an inspector to re-examine a forging periodically to determine if some type of failure is starting after a given service life. The forging may also be checked after minor accidents to see if any flaws have developed. All these inspections are made absolutely non-destructively and usually with a relatively short outage time.

Ultrasonics looks inside the metal

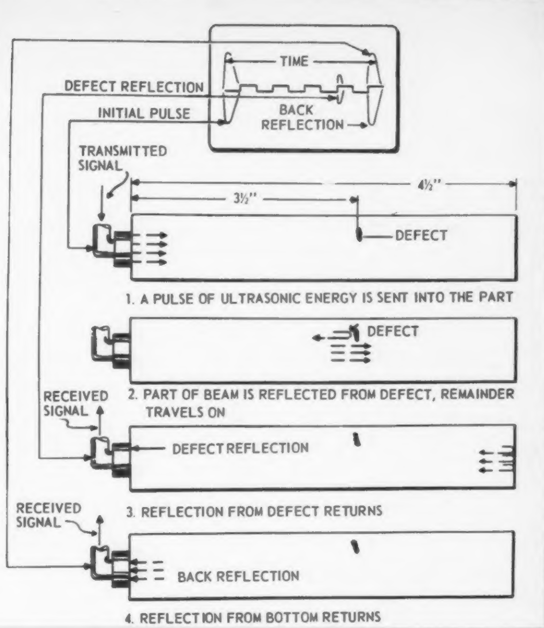
What is ultrasonics and how does it work? The word "ultrasonic" refers to high-frequency sound waves above the audible range, including all those waves above 20,000 cycles per second. Frequencies normally used in ultrasonic inspection are 0.5, 1.0, 2.25 and 10.0 megacycles. However, for special applications, frequencies of 0.2, 15.0, 20.0, and 25.0 Mc are used. The transducer, or search unit, is a piezoelectric quartz crystal that is vibrated by electrical impulses against the surface of the piece being tested. Ultrasonic waves are introduced through a liquid coupling into the material and then transmitted and reflected within the material. The necessary electronic circuits are shown in Figure 2. Figure 3 shows the transmittal and reflection within the piece, together with some of the basic terms. The "pulsed longitudinal" test method, using a single crystal acting as both the transmitter and receiver, is explained in Figure 3. Figure 4 shows the "shear wave" method using a single crystal. A simple explanation of the two different type waves is shown in Figure 5.

Another important method, shown in Figure 6, uses two transducers or search units. The electronic circuits are fundamentally the same, the main difference being that one crystal is used as a transmitter, the other as a receiver.

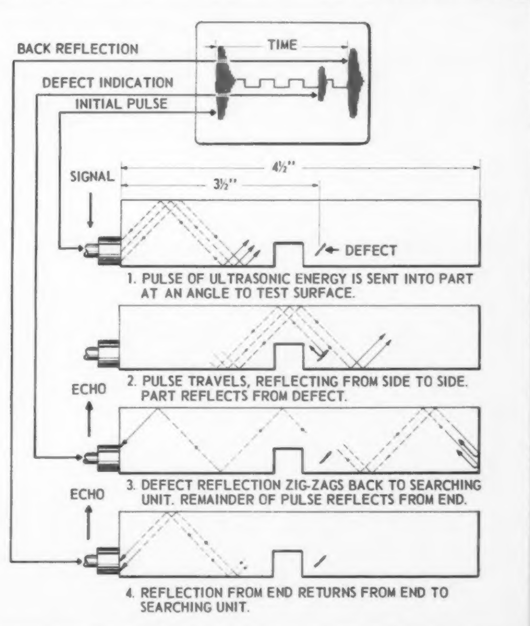
Ultrasonic testing can determine if any tool marks or cracks are hidden between mating surfaces. A transducer sends an ultrasonic wave parallel to the surface, and from 0.050 inch to 0.110 inch below the surface of the piece being tested. Curved surfaces can be tested with transducers, or search units, which are ground to fit a specific curvature. Units are also available which send the sound beam into the piece at angles from 45 to 85 degrees in 5-degree increments. Some units have the crystal mounted so that any angle from 0 (90 degrees) to 45 degrees can be obtained by rotating the head of the unit. These search units are all used to solve specific problems when a special condition exists. Search units which can be used to perform various tests are shown in Figure 7.



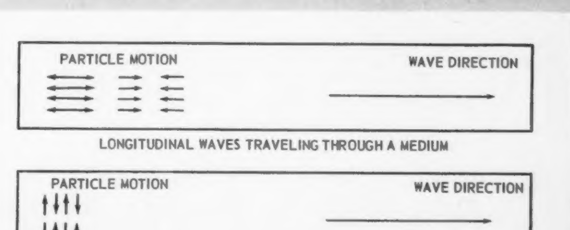
BLOCK DIAGRAM of the reflectoscope includes all the required components and their necessary connections. Permanent records of tests can be made by photographing the tube face. **(FIGURE 2)**



REFLECTOSCOPE with a single search unit directs wave through piece. Part of wave that hits defect is returned sooner than remaining part of wave reflected back from end of the piece. **(FIGURE 3)**



SEARCH UNIT sends wave across axis of piece, wave is reflected from each side, and finally retraces its pattern back to the search unit. When wave hits a defect it is reflected back to search unit in less time, appearing ahead of the back reflection. **(FIGURE 4)**



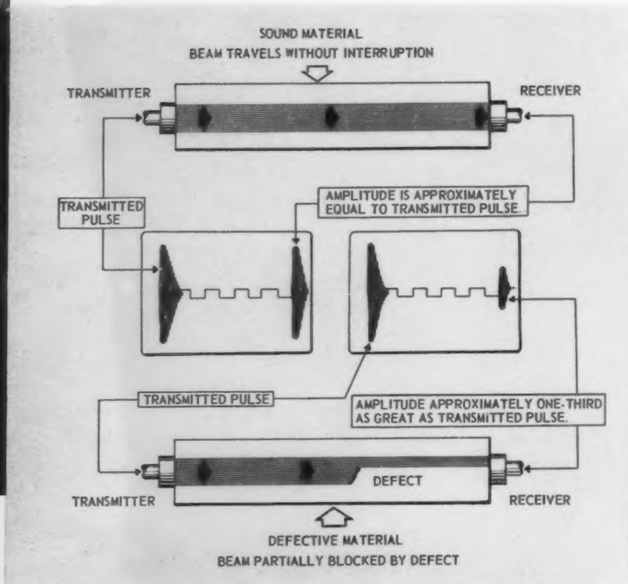
IN PULSED LONGITUDINAL METHOD, waves and particles both travel along axis of part. In shear wave method, while the waves travel through part, particles move across axis of part. **(FIGURE 5)**

Thorough testing guarantees quality

Consider the spindle shaft as an illustration. After the spindle shaft has been forged, it is subjected to one of the most comprehensive quality control inspection procedures possible. Ultrasonically, it receives a minimum of four tests and may get as many as eight to ten tests before it reaches final machining. Ultrasonic tests are designed to detect a defect at any stage in the manufacturing process.

The first quality control checks on the spindle forging can be made on the ingot. The ingot, a cast-steel basic shape from which forgings are made, can be tested ultrasonically to determine its internal soundness. This procedure will save man-hours and machinery costs on a forging that might ultimately be scrapped because the basic unit was faulty. Conditions such as primary and/or secondary pipe, excessive porosity, or other gross defects are searched out. Locally ground spots, regularly spaced on a longitudinal band, can be used in inspecting the ingot. At 0.5 Mc any defects can be plotted and recorded. After the test, the ingot is placed into one of six classifications, such as 1A, 1B, 2A, 2B, 3A or 3B, ranging from the soundest at 1A to the poorest at 3B. The forge shop then determines the fitness of the ingot for a particular forging, the forging reductions necessary to produce a sound forging from the particular classification available, and other facts necessary for the production of a sound forging. Figure 8 shows reflectograms from a 1A ingot and Figure 9 from a 3B ingot.

The following test detects forging defects that may have occurred or developed during the forging operation. From four to six circular spots are milled on each end of the shaft and at several additional locations on various diameters where experience has shown that danger points may exist. All areas are then tested at 1.0 Mc, and photographic records are made of the sonic pattern. If this test



WITH TWO CRYSTAL through method, transmission pulse enters the end of part, but only wave portion that is not deflected by a defect continues through part to be picked up by receiver. **(FIGURE 6)**

SEARCH UNITS of many types are used. Crystal assembly, top center, is used as transmitter and receiver, hinged to permit use on different diameters. Unit in upper right-hand corner is used in shaft bores. **(FIGURE 7)**

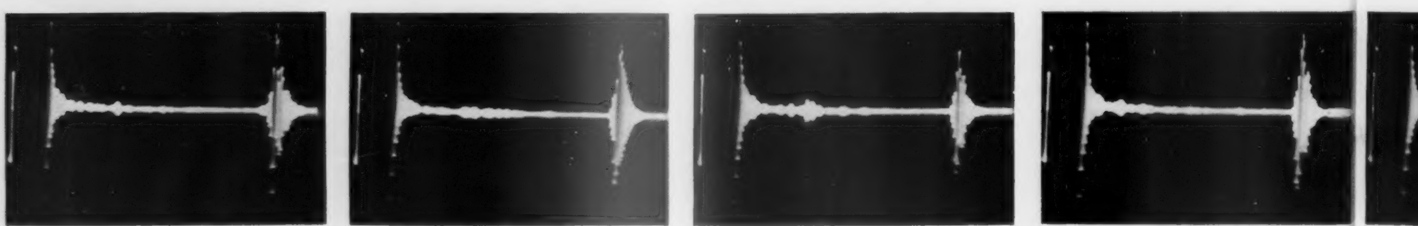
reveals questionable areas, they are investigated further, either by additional sonic tests or by making a short preliminary bore, or both. In case of a bad center condition in the shaft, the necessary bore size is determined to produce an acceptable bore.

New method inspects shafts in a lathe

The first of three tests is then made and the three tests will be used as the ultrasonic basis of acceptance or rejection of the forging. The tests are all performed in the same manner, but are made at different stages of manufacture. This technique was adopted primarily to determine the presence of hydrogen flakes, and to differentiate between dirt inclusions and flakes.

The ASTM Subcommittee VI Task Force on Brittle Failure of Steel Forgings was instrumental in providing open discussions of this method* of ultrasonic inspection which led to its widespread use on electrical forgings. The test uses the "double-crystal" method, with two search units, one to transmit the signal and the other to receive. Figure 10 shows the arrangement with accompanying reflectograms to illustrate what takes place when the "double-crystal" method is used. When using this technique, two distinct types of sonic indications may be noted. The first type, called "stationary," are those indications normally associated with inclusions, bursts, or other gross defects. The second type produces "traveling" indications, which are usually associated with mid-radius defects of the flake category.

For this test, the shaft is bored and the test surface is given a suitable finish for testing. This surface is given a "phonograph" finish on the turn, produced by controlled feeds and speeds, with the lathe tool ground to a particular radius. There are two reasons why this finish is used instead of the old 125 micro inch surface. First, it is easier and less expensive to produce, and second, more even contact with the couplant and surface can be obtained. For the test, the shaft is rotated in a lathe, usually at a speed not exceeding 6 surface inches per second. Longitudinal crystal travel is ¾ inch per revolution. The crystals are resonant at 1.0 Mc and are of the 1 inch square or round type. The frequency 1.0 Mc is used because of the divergence of the sound beam, approximately 30 degrees, which produces the results shown in Figure 10. The standard used during the test is designed so that even small isolated inclusions will be detected. The "back reflection" is adjusted to 3 inches on each diameter tested, and all indications of 5 percent of the back reflection and greater are plotted and made a part of the information file on the shaft. The "double-crystal" test is applied the first time



SOUND PATTERNS in ingot show very little distortion, indicating that metal contains no defects that weaken metal structure. Several patterns are recorded to thoroughly examine the piece. **(FIGURE 8)**

after rough machining, prior to heat treatment for physical properties; the second time immediately following heat-treatment for physical properties; and the third time following the heat stability test. The results of the three tests are recorded, compared, and the shaft acceptance is based on these results.

Experimental work is being carried on to develop a technique whereby a shaft can be inspected by placing the crystal in the bore, as shown in Figure 11. The test could be performed on the shaft after blading, balancing and overspeeding have been completed — just prior to shipment. A complete ultrasonic record could also be made of the entire length on movie film. Similar tests could be made on the shaft at any future time, or after a given number of service hours. The slightest change in the ultrasonic pattern could be detected immediately and a complete and intensive investigation made. Figure 12 illustrates how ultrasonics can also check the depth and location of slots and radial thickness of a shaft.

The precision with which ultrasonic testing can be used is illustrated by the manner in which a defect was removed from a spindle shaft. The defect was discovered near the position of a turbine blade requiring a milled slot. It was decided that the defect could be removed for examination if the shaft were trepanned at 15 degrees from the normal. Ultrasonics pinpointed the defect in the shaft interior. The trepanned bar carried with it two large silicate inclusions found within the ¾-inch radius of the bar.

Ultrasonic testing is versatile

Tests and techniques used on a spindle shaft have been discussed in detail. The same type of tests, at various stages of manufacture, are applied to a number of other forgings used in the turbine. The "double-crystal" technique as well as single-crystal techniques are used on spindle rings, coupling gears and flanges, and generator rotor shafts. Single-crystal techniques are applied to manifolds, Y connections, stop valve bodies, stud bolts, and other miscellaneous forgings.

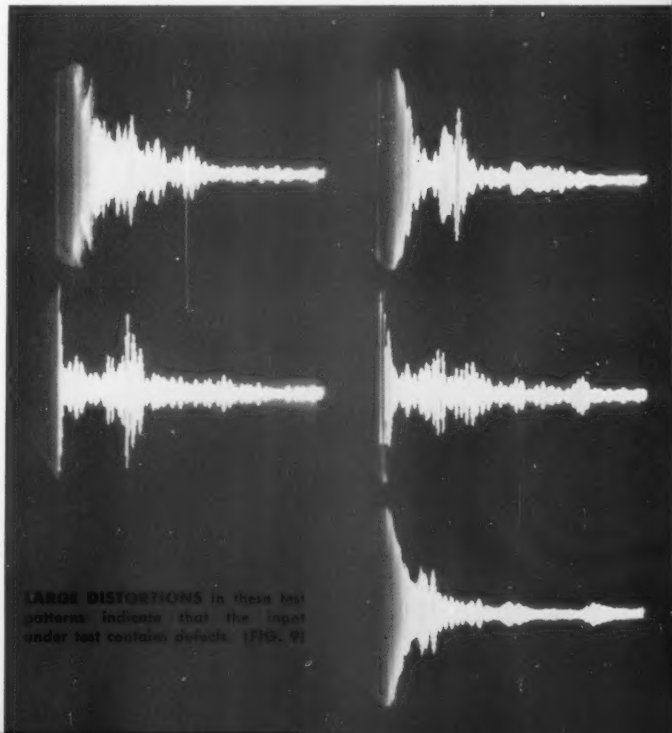
Ultrasonic testing is readily applicable to testing stud bolts. The single-crystal technique at 10.0 Mc is applied to the forging. The crystal is applied only to the exposed face of the bolt after removal of the cap nut — while still in position in the cylinder — and cracks 0.050 inches deep or greater at the roots of the threads are detected and isolated. Several hundred bolts have been tested, with the results proving the value of the test.

High temperature steam pipes may also be tested by ultrasonics. For pipe testing, a crystal producing a "shear wave" is used. For small diameter pipe, under 6-inch O.D., a shoe made of lucite, or similar material, is placed over the crystal. The face of the shoe that contacts the pipe is ground or fitted to the diameter of the pipe being tested. In this way good contact is maintained. For larger diameter pipe, the crystal is placed directly in contact with the testing surface. Pipe requiring testing is examined a minimum of three times. The pipe is tested after manufacture at the vendor's plant, after the bends and other fabrications are completed, and finally tested in the field on the welds made during final installation. Standards that have been checked against X-ray and microscopic examination assure that each pipe and pipe weld are as sound as it is possible to make them.

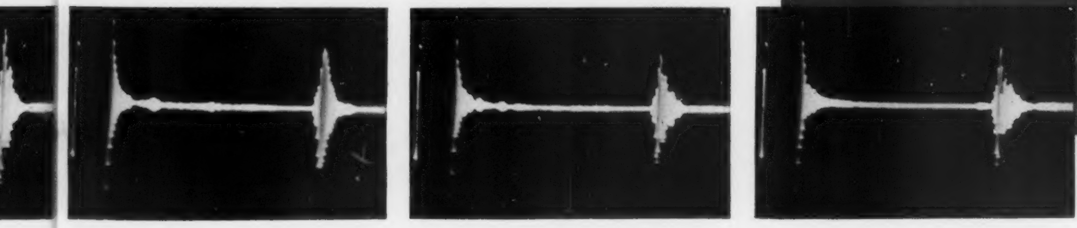
Several additional parts of the turbine and generator are ultrasonically tested. The rotor coil support rings are tested three times during their manufacturing cycles. All the plate used for stator yokes is checked for laminations and segregation. Commutator bars are tested to insure that no cracked or broken bars are in the final assembly. Castings that have been X-rayed are ultrasonically tested to determine the depth of objectionable defects so that they may be removed with the least amount of gouging and repair.

Research enlarges test range

A great amount of additional investigational work is being carried on to further the development of ultrasonic testing



LARGE DISTORTIONS in these test patterns indicate that the ingot under test contains defects. (FIG. 9)

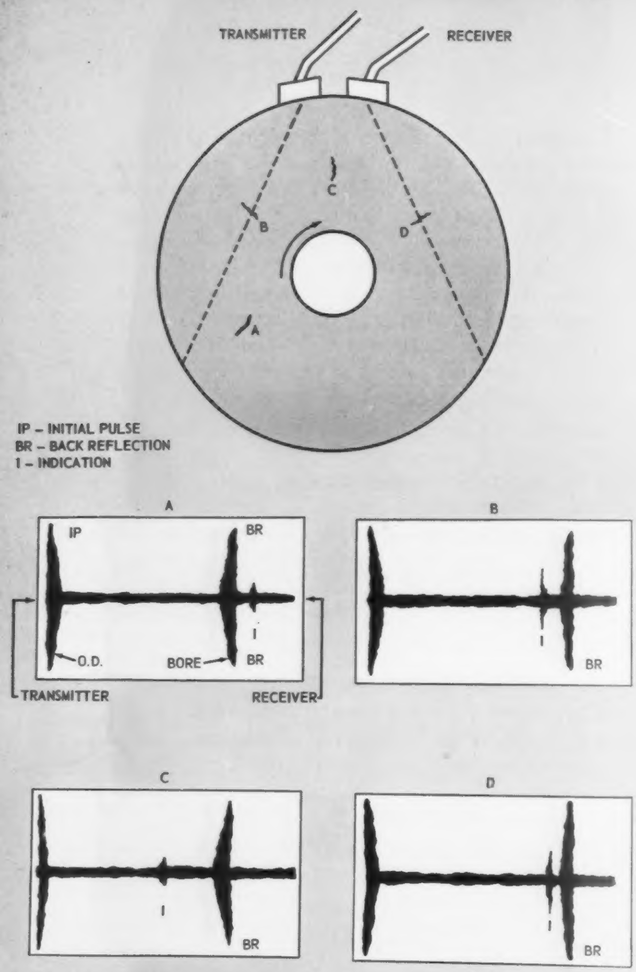


in addition to the routine methods that have been discussed so far. Efforts are being made to accurately identify the size, shape, and type of defect noted in finished forgings. Experimental work is being carried on to determine the quality of the brazing operation performed on the stellite inserts of turbine blades. New test methods are also being investigated to test various turbine installations that have been in operation for a number of years and for which no previous test record is available. Additional work is being carried on to determine by means of ultrasonics the internal condition of various material found in pumps, motors, pipes, and stud bolts. Ultrasonic testing has become one of the standard inspection methods used for producing the soundest possible turbine parts and for their continued inspection during their operating life.

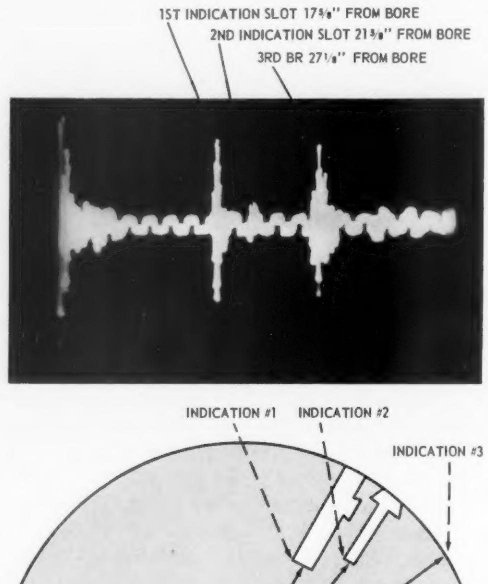
REFERENCES

*"Acceptance Guide for Ultrasonic Inspection of Large Rotor Forgings," A. W. Rankin and C. W. Moriarty, ASME *Transactions,* Vol. 78, No. 7, pp 1603-1622, October 1956.

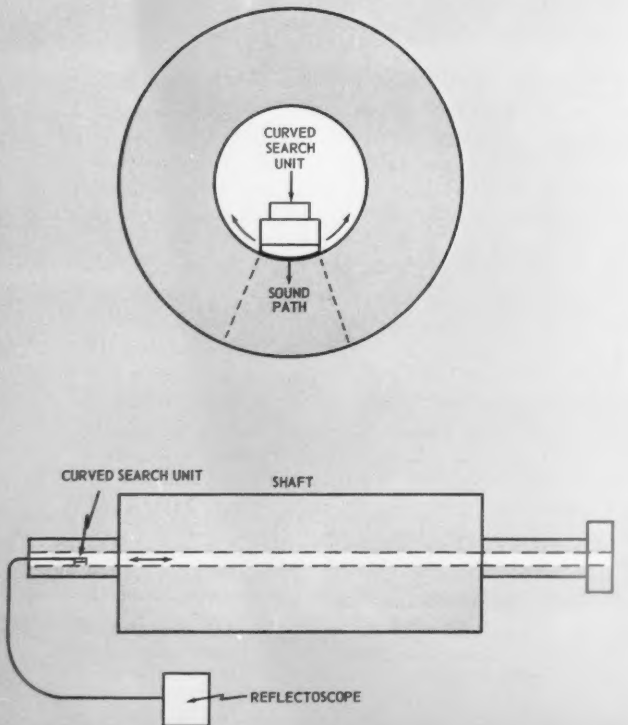
Ultrasonics, Benson Carlin, McGraw-Hill Book Company, Inc., 1st edition, 1949.



ONE CRYSTAL sends waves and other crystal receives them while shaft revolves. The letters on the shaft section correspond with the letter identifying each reflectogram. The indication "I" is the same discontinuity as noted while shaft rotates. **(FIGURE 10)**



REFLECTOGRAM shows two milled slots and outer turn picked up with search unit in shaft bore. Distances measured through shaft agree with scale distances on the reflectogram. **(FIG. 12)**



CURVED SEARCH UNIT fits shaft bore. Unit is pushed through bore and the reflectoscope indicates any discontinuity in shaft as unit passes over a flaw. Search unit with its three-point contact is in upper right-hand corner of Figure 7. Either the shaft or the search unit may be rotated to new test position. **(FIGURE 11)**

Are PATENTS Helping You Solve Your Problems?

by **HOUSTON L. SWENSON**
Patent Department
Allis-Chalmers Mfg. Co.

A cumulative file of organized patent information will enable an engineer to use past discoveries to develop future projects.

THERE'S A SHORT CUT to most things in business as in any other field. In the engineering phase of business, patents can help in finding this path. For, in effect, patents are recipes to solutions of engineering problems.

Approximately 35,000 patents are issued by the United States Government every year. The grant of each patent gives the owner the right to exclude others from making, using or selling his "brainchild." These patents cover all phases of engineering and each patent contains a detailed description of an invention. Copies of patents or recipes on any particular phase of engineering are readily available to the public at a nominal charge. And that's where the recipe box for an engineer comes in.

When an engineer has a recipe box at hand — that is, a well-organized file of patents relating to his particular field of engineering — he can quickly find a clue or many clues to a solution of a design problem. It is quite possible that he may find the solution because of the contents of a very old patent, long since forgotten. And he may find clues to some of his contemplated avenues which have proved out to be dead ends because somebody else has already tried and failed.

How does an engineer, or a company for that matter, make a start on setting up a recipe box?

Official gazette classifies patents

The *Official Gazette* issued by the United States Patent Office is a weekly publication and contains a short synopsis of each patent issued during the preceding week.

By having a subscription to the *Gazette,* costing $30.00 a year, an engineering department can keep abreast of all new patented inventions. But with over 700 patents issuing each week, you might ask how can engineers afford to give up valuable time in reading the *Gazette.*

It's not at all difficult or time-consuming once you understand the setup of the *Gazette.*

The newly issued patents have been classified into three sections: general and mechanical, chemical, and electrical.

PATENT ENGINEER locates the subject covering specific idea for the engineer in the subject classification index. The patent index locates the applicable patent in the patent file. **(FIGURE 1)**

Therefore, if you're concerned with a polyphase transformer phase converter system you would turn to the electrical section, skipping by the mechanical and chemical sections. But be careful! Even though you're dealing in electrical equipment, insulating material may appear in the chemical section and a particular type of transformer bracket may appear in the mechanical section. So often it is worth-while to glance through all three sections. Once you become familiar with the *Gazette* this will require little time.

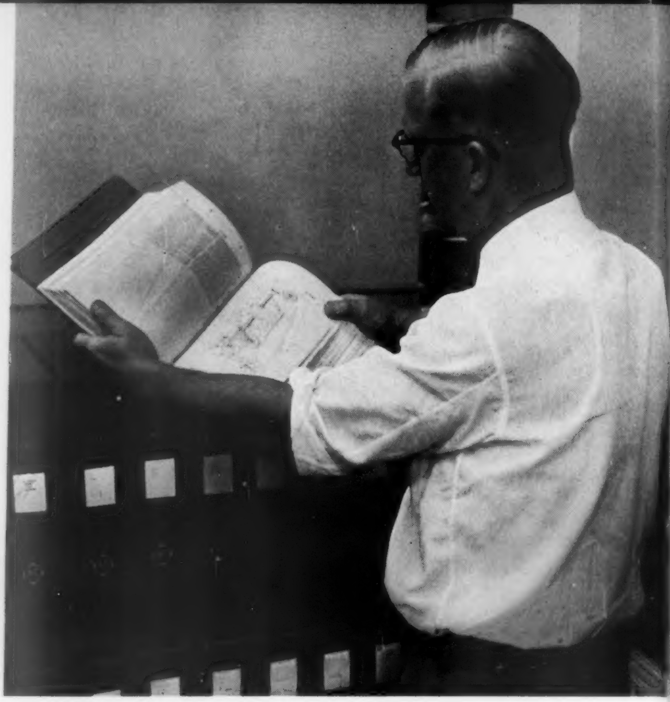
Upon noticing a patent which has particular interest for you, you'll want to obtain a copy of it. For 25 cents you may obtain a copy of a United States patent from the Commissioner of Patents, Washington 25, D. C. The Patent Office has books of coupons available for purchase that will make ordering patents an easy job.

Subclass numbers identify subject groups

For quick reference the Patent Office has established a numerical classification system, indexed as the *Manual of Classification.* For example, inductor devices have been designated as class 336. Underneath this class are subclasses, such as 336-197 for coil clamps or wedges. So if you're concerned with clamps for transformer coils, you'll be interested in obtaining patents issued under 336-197. Although you can keep a close check on any patents issuing under this subclass by looking in the *Gazette,* you may prefer to request that the Patent Office send you all patents issuing under this class. In this manner you'll eliminate a lot of weekly ordering and will also be certain of not overlooking a patent in this subclass. The *Manual of Classification* lists the subclasses containing your pertinent art and may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D. C. The accompanying page of the *Manual* shows the organization of items under class 336.

Another alternative is to have the attorney handling

THE ENGINEER SHOWS the patent engineer a brief description of an invention or idea. Patent engineer has consulted his index and found the subject concerning the engineer's idea. **(FIGURE 2)**



THE ENGINEER EXAMINES ONE of the applicable patents in patent file that pertains to his idea after the subject classification index has located his necessary information. **(FIGURE 3)**

your patents matters forward you the pertinent patents. Unless such attorney is closely associated with your work, you'll probably prefer to make your own selection of patents.

If your engineering development work is fairly broad, a large quantity of patents will soon be accumulated. Don't just stack them away in that bottom drawer as they come in each week! Arrange them in a systematic order. Otherwise you'll have a hodgepodge that will discourage anyone from using them. Granted, you the orderer, may be able to remember what patents you have. But could your fellow engineers or the person who takes over your position upon your promotion make efficient use of the patents?

Card file serves several systems

A recipe box, regardless of its contents, should be built on a filing system. One system is known as the classification system, which is based on the subject matter of the patents. If you're primarily engaged in designing transformers, you may want to reserve a section of your file for the construction of cores, another to windings, and another to protective devices. Casings, cooling systems, and potential and current transformers can be titles for other sections.

Another part of your file can be arranged for miscellaneous. If this section becomes too large, perhaps it's an indication that you need to add another title. As your number of patents increases, you may want to subdivide your title or classes. For example, cores could be divided into wound cores and laminated cores.

As each new patent reaches the department, the person in charge, usually the patent engineer, makes a 3 x 5 card to include the pertinent information for a particular patent. The card effectively locates a particular patent without looking through the several possibilities given in the patent index. To locate in the future a specific patent in your file identified by number, you may want to make a 3 x 5 card for each patent, giving the patent number, title, inventor, and designated class. These cards are arranged numerically according to patent numbers.

Of course, if you're concentrating on a very narrow field of engineering which is divisible into only a few classes, you may not find the subject matter classification system suitable to your needs. Some engineering departments have found it desirable to file patents according to the owners of the patents. This type of file enables you to readily keep abreast of the work being done by your competitors. Another system is to file the patents numerically. With this type of system you can quickly find the most current patents or patents issued in a particular period and will not need a card index file to find a specific patent. Whatever filing system you may choose, be sure that it's not so complicated as to discourage use.

One engineering department which has been highly successful in development work has chosen to use a combination of the above filing methods. Its patents are broken down into classes according to subject matter. The classes have been given numerical headings similar to those of the United States Patent Office classifications. An index book is used by the engineers to determine the class number of a particular subject. The department also uses a card file. A card is made out for each patent in its file and bears the patent number, title, inventor, patent application filing date, patent issuance date, and the class number showing where the patent is filed. These cards are numerically filed according to patent number. The department has also maintained a list of the patents held by their competitors and the class numbers of such patents.

Patent files save valuable time

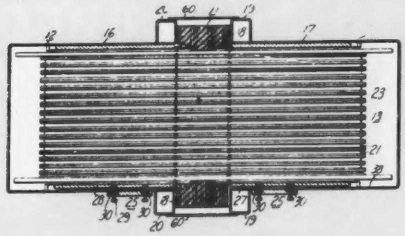
Engineering departments have found that more actual use is made of the information in the patent files if the engineer has a working knowledge of the location of the files and the type of filing system that is employed.

Recently an engineer who was concerned with developing a higher quality of magnetic steel saved himself a lot of work and his company a lot of expense by referring to his department's patent file. In it he found several patents which contained data on experiments he had contemplated running.

He thereby eliminated much research and was able to couple his own knowledge and ingenuity with information gained from the patents to provide a solution to his problem. The result was a vastly improved material with relatively low cost.

The United States Government has a valuable pool of information in its Patent Office. Many ideas will stay buried in the Patent Office files unless the engineer, realizing that such gems of information exist, makes up a useful file of patents applicable to his work. An engineer with his valuable background and training can make full use of patents in his development of new ideas and products.

2,774,047
COIL CLAMPING DEVICE FOR A TRANSFORMER
Harding B. Hansen, Elm Grove, Sten S. Stenersen, Milwaukee, William C. Sealey, Wauwatosa, and Karl P. Wiederkehr, Elm Grove, Wis., assignors to Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Application October 4, 1954, Serial No. 459,894
5 Claims. (Cl. 336—197)



5. An externally operable device for clamping a plurality of disk coils and insulation within an enclosing tank of a transformer in which the magnetic core forms an integral part of said tank, said device comprising a rigid plate disposed parallel to the plane of said coils intermediate said assembly and a wall portion of said tank, a plurality of guide sleeves fixedly attached to said plate in predetermined spaced relationship, each of said sleeves disposed with its axis normal to the face of said plate, means associated with said wall portion for receiving said sleeves to position said plate with respect to said assembly, and individual jack bolts associated with different ones of said sleeves, each of said bolts extending in threaded engagement through a wall portion of said tank with the ends of said bolts disposed in their associated sleeves whereby said plate is moved against said assembly by a turning action of said bolts.

OFFICIAL GAZETTE lists newly issued patents in numerical sequence and class number as in *Manual of Classification*. Information will help engineer to decide whether his idea will conflict with patent already issued. (FIG. 4)

January 1956 — CLASS 336, INDUCTOR DEVICES — 336-1

Original Classification H. Gauss 1952
Subsequent Revision S. W. Capelli, H. Gauss
J. Stitelman
Definitions in Bulletin No. 404

5	POLYPHASE
10	Adjustable inductor
12	Interconnected windings
15	WITH COIL WINDING AND/OR UNWINDING
20	WITH DEFORMABLE OR DISTORTABLE COIL AND/OR CORE
30	WITH CONDITION RESPONSIVE INDUCTANCE ADJUSTING MEANS (e.g., BY ELECTROMAGNET)
40	ADJUSTABLE BY MAGNETIC FORCE BETWEEN RELATIVELY MOVABLE PARTS OF THE INDUCTOR
41	Weight counterbalanced coil or core
45	WITH MOVABLE ELEMENT POSITION INDICATOR
55	WITH TEMPERATURE MODIFIER
57	With inductor insulating fluid circulating means
58	Liquid insulating medium
59	Vented casing
60	Ventilating passages (e.g., by coil section or core part spacers)
61	Heat exchanging surfaces
62	Hollow conductor coil
65	WITH MOUNTING OR SUPPORTING MEANS (e.g., BASE)
66	Handle
67	Bracket
68	Suspension
69	WITH COIL CAPACITANCE MODIFYING MEANS
70	With surge potential gradient modifying means
73	WITH CLOSED COIL OR CONDUCTOR MEMBER
75	Movable with respect to another coil
77	With magnetic portion
79	Angularly movable
82	COIL FORMS PROTECTIVE CASING
83	CORE FORMS CASING
84	WITH ELECTRIC AND/OR MAGNETIC SHIELDING MEANS
87	Adjustable inductor
90	WITH OUTER CASING OR HOUSING
92	Internal inductor support
94	Fluid insulation
96	Potted type
98	Exposed core portions
100	WITH VIBRATION CONTROL
105	COMBINED
107	With connector
110	WITH PERMANENT MAGNET
115	RELATIVELY MOVABLE COILS
116	With means to change coil length and/or connections
117	With core
118	Relatively movable core and coils
119	Coil and core movable as a unit
120	Angularly movable
121	Angularly and linearly movable coils
122	Angularly movable
123	About axis parallel to or coaxial with the other coil axis
124	Non-symmetrically pivoted coil movable on axis transverse to other coil axis
125	About axis normal to other coil axis
126	Plural coils movable with respect to a coil
127	Similar spherical shaped coils
128	Tubular stationary coil
129	Movable along or parallel to other coil axis
130	RELATIVELY MOVABLE CORE AND COIL
131	Plural coils with plural cores
132	Plural relatively movable core parts
133	Adjustable magnetic shunt
134	Adjustable air gap
135	Angularly movable
136	Telescoping magnetic body and coil
137	WITH MEANS TO CHANGE COIL LENGTH OR CONNECTIONS
138	Parallel spaced conductors or coils bridged by movable connector
139	Contactor following helical conductor
140	Plural movable contactors
141	With contactor guide track
142	Coil connections changed by moving coil (e.g., coil substitution)
143	With connection reversing means
144	With variable number of short-circuited turns
145	Plural coils (e.g., transformers)
146	Inductance change in plural coils
147	Plural coils or coil portions connected in parallel or in series and parallel
148	Autotransformers
149	Contactor slidable on coil winding
150	Series change (e.g., tap change)
155	INDUCTIVE REGULATORS WITH NO RELATIVELY MOVING PARTS
160	With magnetic shunt to increase leakage reactance
165	Air gap in magnetic shunt
170	THREE OR MORE WINDINGS
171	Non-inductively related windings
172	COIL TURN LINKS PORTION OF CORE CROSS SECTION (e.g., FRACTIONAL TURN)
173	INTER-LINKED COILS OR WINDINGS (e.g., CURRENT-TRANSFORMER)
174	Coil surrounding linear conductor
175	CORE SURROUNDING LINEAR CONDUCTOR
176	Hinged core
177	WITH COIL OF MAGNETIC MATERIAL
178	WITH CLOSED CORE INTERRUPTED BY AN AIR GAP
179	COILS WITH TEMPERATURE COMPENSATING MEANS
180	WINDING FORMED OF PLURAL COILS (SERIES OR PARALLEL)
181	Wound to reduce external magnetic field (i.e., fieldless winding)
182	Two windings (e.g., transformer)
183	Coils of different windings interposed
184	Coils having different axis or on different core legs
185	Coil supports or spacers
186	COIL FORMED OF PARALLEL CONNECTED CONDUCTORS
187	Crossed or transposed conductors
188	TWO WINDINGS WITH MUTUALLY CROSSED WINDING TURNS
189	COIL WITH CROSSED TURNS
190	Bank or universal wound coils (e.g., honeycomb, random wound)
191	Basket weave (single layer)
192	WINDING WITH TERMINALS, TAPS, OR COIL CONDUCTOR END ANCHORING MEANS
195	COIL SUPPORTED WITHIN GROOVED OR HOLLOW COIL CONDUCTOR OF ANOTHER COIL
196	WITH SUPPORTING AND/OR SPACING MEANS BETWEEN COIL AND CORE
197	Coil clamps or wedges
198	Preformed insulation between coil and core (e.g., spool)

197 Coil clamps or wedges

MANUAL OF CLASSIFICATION page contains class and subclass of inductor devices with coil clamps or wedges. (FIGURE 5)

VARIABLE-SPEED PUMPS...

Their Motors and Control

by **R. L. BROWN**
Centrifugal Pump Dept.
Allis-Chalmers Mfg. Co.

SPLIT CASE VARIABLE-SPEED PUMP can be used as booster in distribution system to meet varying load conditions. Pump speed varies with the system demand for efficient operation. **(FIGURE 1)**

Many pump applications have changing output requirements. Variable-speed pumps driven by ac commutator motors will meet these needs with appreciable operating economies.

IN NEARLY ALL PUMPING APPLICATIONS, but particularly in the water supply and sewage disposal field, the flow of water or sewage varies through the day. The quantity pumped must be controlled to equal the demand on, or drainage from, the system. Because of the fixed head-quantity relationship for a constant-speed centrifugal pump, the problem is usually partially solved in two ways: first, by intermittent pumping and providing storage tanks or sumps to even out peaks and hollows in the demand; and second, by continuous pumping, with any excess head available from the pump being absorbed in a pressure-reducing valve or at the consumer's faucet. The latter method does not normally apply to a drainage system and is only used in water supply practice.

In the larger installations, pumps of various capacities are used in combination and in series-parallel arrangements. The storage tank or sump must always be sufficiently large to avoid excessive wear on the pumps, motors, and control by too frequent starting and also to prevent the possibility of hydraulic surges being set up in the system. In a water supply application the storage tank is very often big enough to provide a reserve in case of a breakdown in the pumping plant, or meet an exceptional demand to combat an outbreak of fire. This emergency storage must be in addition to that necessary to smooth out the irregularity of demand.

To avoid the high capital cost of storage tanks and sumps, and at the same time give more economical and greater flexibility of operation, it has been common practice to use variable-speed pumps driven by variable-speed motors so that both quantity and head can be varied to meet the requirements of the system. Included in the variable-speed pump and motor combinations is the possibility of using an ac commutator motor to drive a variable-speed pump.

Variable-speed pumps have many applications

Variable-speed pumps have been used to advantage in the following types of applications:

(*a*) *Recirculation of Effluent in a Sewage Treatment Works*

Filtered effluent is added to the raw sewage after sedimentation to give a constant flow to the filter beds. The total flow requirement is usually set manually, depending on the number of filters in service, the quantity of recirculated effluent being automatically adjusted to make up the difference between the incoming sewage flow and that preset for optimum efficiency of filter operation.

(*b*) *Deep-Well Pumps*

Speed is adjusted to suit well level and also water demand if the pumps are delivering direct into a distribution system with no intermediate contact tank. During periods of highest demand, well levels are usually lowest and vice versa, calling for fairly wide speed ranges.

(*c*) *Pumping Sewage from a Central Collecting Point to Treatment Works*

Instead of starting and stopping constant-speed pumps according to well level, variable-speed pumps are controlled automatically so that the

quantity delivered exactly matches the incoming sewage flow. Pump sumps can be very small or entirely eliminated.

(*d*) *Pumping into Water Distribution Mains to Meet Varying Demand*

One or more variable-speed pumps are automatically controlled to give a constant pressure at the end of a distribution system, regardless of the quantity of water drawn off by consumers. Sometimes it is necessary to provide a storage tank for breakdown or emergency purposes, but generally, when the plant is used for booster service only, a storage tank is not needed.

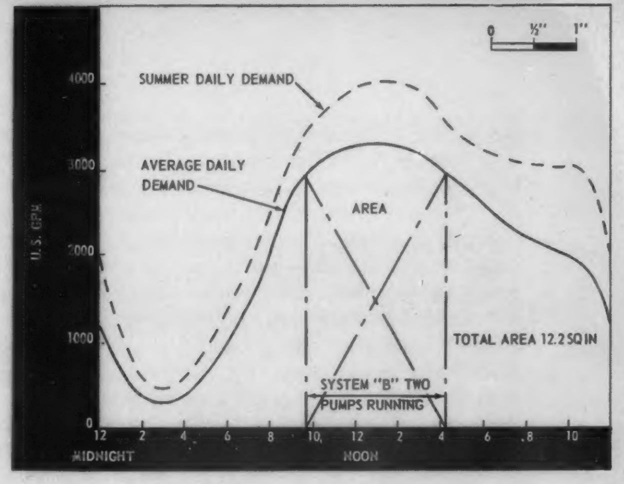
(*e*) *Temporary Storage of Storm Flows*

Often it is cheaper to divert storm water temporarily from a drainage system into storage tanks until the peak storm flow has receded rather than install a larger sewer or possibly replace an existing one. Variable-speed pumps have been used to lift water from storage and put it back into the sewer at a maximum rate during a recession in the storm and so continuously keep the full capacity of the sewer in readiness for a further storm outbreak. Control is based on the flow in the drainage sewer, but owing to the speed at which conditions can change in such a system, it is desirable to build a warning into the control arrangement. The warning indicating a future increase in the storm flow would be received from a differential rain gauge located in the gathering area, giving a bias to the normal control to indicate that flows may soon increase.

Greater operating economies realized

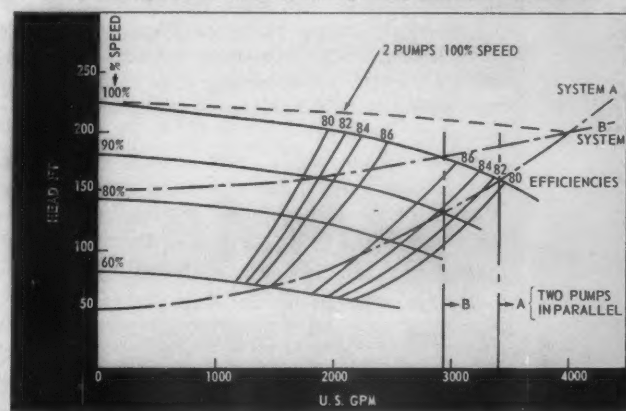
It is difficult to generalize whether variable-speed pumping is more economical than constant-speed pumping, but it can be safely said that the greater the proportion of frictional head in the total head, the greater the possibility of realizing savings with variable-speed operation. Consider a system which is entirely frictional with constant-speed pumps operating at 200 percent capacity 12 hours per day, as compared to smaller pumps operating at 100 percent capacity 24 hours per day. Because of the square law quantity-friction loss relationship, the water horsepower hours necessary to carry out the first supposition will be exactly double that of the second. The conclusion drawn from the two illustrations is admittedly an over-simplification, but it serves to illustrate the point.

Consider a water supply application with no storage on the discharge side of the pumping station, as might occur with a booster station. Figure 3 shows the characteristics of two similar pumps designed to meet the average daily water demand curve shown in Figure 2. Two cases are considered: first, System A having 50-ft static head and 150-ft friction head at the maximum quantity of 4000 gpm; and second, System B having 150-ft static head and 50-ft friction head at the same quantity. The pump curve has been chosen to suit both these conditions so far as possible, but it is not the best that could be used for either system when considered individually, where improvements in overall operating efficiency could be made. Figures 4

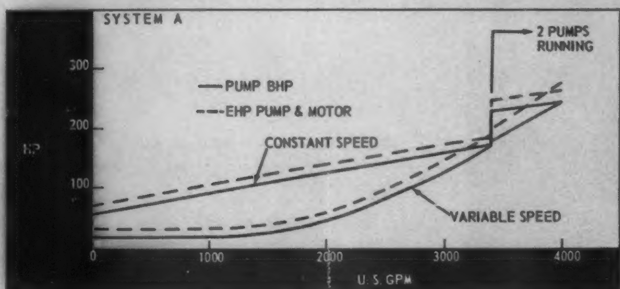


1" = 1000 GPM 1" = 4 HOURS or 240 MIN.
TOTAL QUANTITY = $12.2 \times 240 \times 10^3 = 2.93 \times 10^6$ GALS
QUANTITY WITH 2 PUMPS RUNNING (SYSTEM B ONLY)
= $5.2 \times 240 \times 10^3 = 1.25 \times 10^6$ GALS

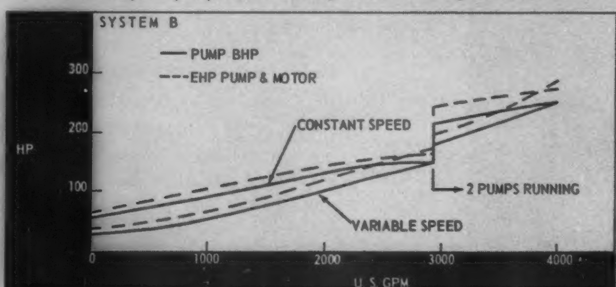
TYPICAL DAILY WATER DEMAND CURVES for distribution system for residential area show amount of water drawn off per day by consumers. Where quantity exceeds 2930 gpm for System B, two pumps will operate to meet the average daily demand. **(FIGURE 2)**



HEAD-CAPACITY AND EFFICIENCY curves show variable-speed pump characteristics from maximum speed down to 60 percent of full speed. Dotted curve is for parallel pump operation. **(FIGURE 3)**



POWER CURVES show brake horsepower taken by pumps and electrical horsepower taken by motors in System A. Excess head developed by a constant-speed pump will be destroyed in a reducing valve. **(FIG. 4)**



POWER CURVES show brake horsepower taken by pumps and electrical horsepower taken by motors in System B. Excess head developed by a constant-speed pump will be destroyed in a reducing valve. **(FIG. 5)**

and 5 show the brake horsepower absorbed by the pumps with Systems A and B, respectively, for variable and constant-speed operation. The constant-speed pumps would run continuously, assuming that any excess pressure would either be destroyed in a pressure-reducing valve or at the consumer's faucet. The variable-speed pumps, however, would always operate at the intersection of a system curve and the head-quantity curve. Figures 4 and 5 also show the electrical horsepower input to the motors, assuming a motor efficiency of 93 percent for the constant-speed pumps and a variable motor efficiency based on Figure 8, curve *B*, for the variable-speed pumps.

Figure 6 shows the variation in water horsepower through the day with System A and the average daily demand curve, Figure 2. Plotted above the water horsepower curve is the electrical horsepower for variable-speed pumping, and above this the electrical horsepower for constant-speed pumping. The area under the curve will be whp/hrs or ehp/hrs, as the case may be, the power saving with variable-speed pumps being 1150 ehp hours and, multiplying by .746, about 860 kwhr per day. Figure 7 shows the similar curves for System B, but here it will be noticed that it is necessary to run two pumps in parallel for quantities exceeding about 2930 gpm. The power saving with variable-speed pumping is 660 ehp hours or 492 kwhr per day.

To illustrate the case of constant-speed sewage pumps drawing from a sump and operating intermittently, as compared with continuously running variable-speed pumps, most of the values previously assumed can be used. The flow into the sump can follow the curve shown in Figure 2, assuming the pump characteristics are as Figures 3, 4 and 5, and with system curves *A* and *B* considered:

System A

Total quantity to be pumped (from flow curve, Figure 2) . . . . 2.93×10^6 gal

Pumping rate (constant speed, from Figure 3) . . . . 2,400 gpm

$$\text{Pumping time} = \frac{2.93 \times 10^6}{3{,}400 \times 60} = 14.4 \text{ hr}$$

Then power consumed per day (constant speed pumps) $= 180 \times 14.4 = 2590$ electrical hp hr

Power consumed per day (variable speed pumps from Figure 6) . . . . 2130 electrical hp hr

Power Saving. . 460 ehp hours

or. . 343 kwhr per day

System B

This system must be divided into two parts: one pump will run for quantities up to 2930 gpm, and two pumps must run in parallel for quantities in excess of 2930 gpm:

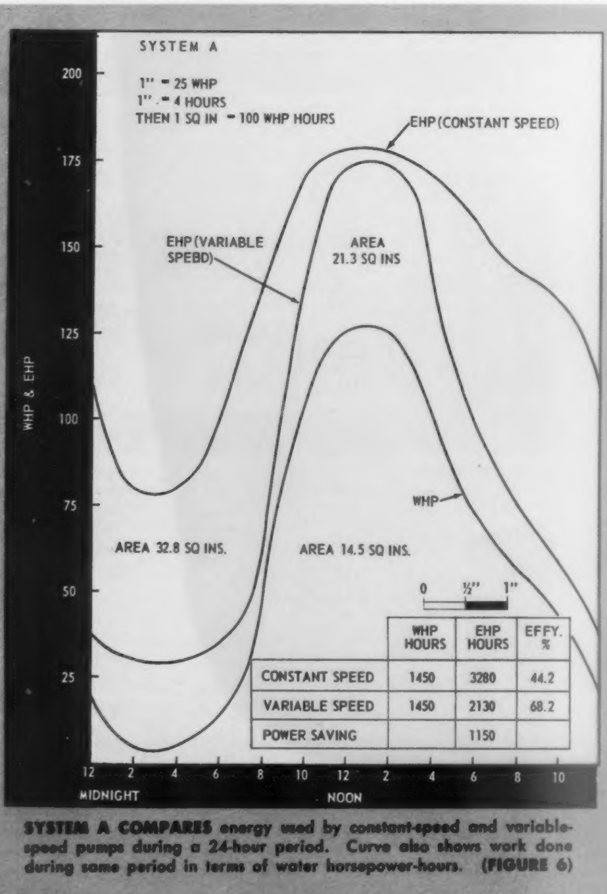
Total quantity to be pumped at 2930 gpm (from Figure 2) . . . . 1.68×10^6 gal

Total quantity to be pumped at 4000 gpm (from Figure 2) . . . . 1.25×10^6 gal

Total power consumption per day

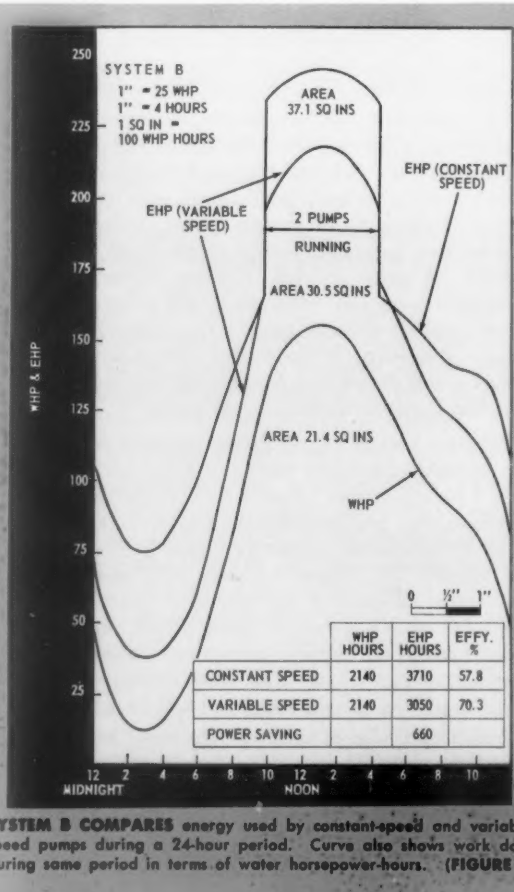
$$\text{will be } \frac{1.68 \times 10^6 \times 167}{2930 \times 60} + \frac{1.25 \times 10^6 \times 270}{4000 \times 60}$$

$$= 3000 \text{ electrical hp hr}$$



	WHP HOURS	EHP HOURS	EFFY. %
CONSTANT SPEED	1450	3280	44.2
VARIABLE SPEED	1450	2130	68.2
POWER SAVING		1150	

SYSTEM A COMPARES energy used by constant-speed and variable-speed pumps during a 24-hour period. Curve also shows work done during same period in terms of water horsepower-hours. **(FIGURE 6)**



	WHP HOURS	EHP HOURS	EFFY. %
CONSTANT SPEED	2140	3710	57.8
VARIABLE SPEED	2140	3050	70.3
POWER SAVING		660	

SYSTEM B COMPARES energy used by constant-speed and variable-speed pumps during a 24-hour period. Curve also shows work done during same period in terms of water horsepower-hours. **(FIGURE 7)**

Power consumed per day (variable-
speed pumps from Figure 7) . . . . . . 3050 electrical hp hr

Additional power required by variable-speed pumps will be 3050 — 3000 = 50 ehp hours or 37.3 kwhr per day.

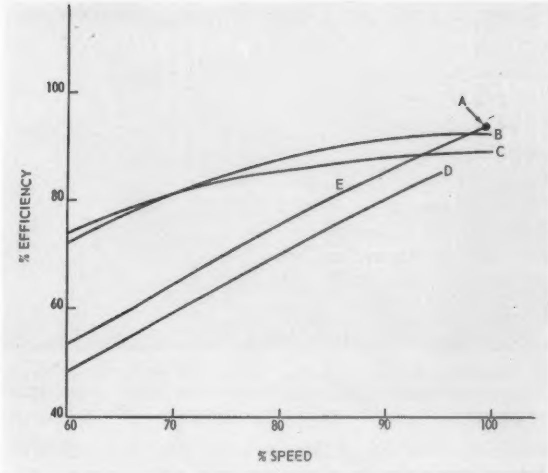
The above examples show that variable-speed pumps with variable-speed motors would probably pay for themselves for an application requiring continuous pump operation with both systems A and B. With the drainage type system having constant-speed pumps operating intermittently, the power saving is not so marked, but variable-speed pumps would probably be most economical for System A, especially when taking into account the capital saving because of the smaller sump size.

Variable-speed motors match load torque

A possible arrangement using an ac commutator motor would result in an appreciable power saving over a relatively wide speed range. When both ac commutator motors and wound-rotor motors are operated at full speed, the power consumed is very nearly the same. However, when speed and torque are reduced, the efficiency of the wound-rotor motor falls rapidly as compared to the efficiency of the commutator motor operating at similar load and speed conditions.

The comparative efficiency of various types of variable-speed drives plotted against percentage speed for a 350/75 brake hp, 1200/720 rpm motor is shown in Figure 8. It has been assumed that the brake horsepower absorbed by the pump varies as the cube of the speed. This assumption is reasonably accurate for a medium specific speed centrifugal pump operating over a limited range. The cost figures for the various types of drive are percentages, 100 percent being the cost of a standard wound-rotor motor with automatic starter and cabling between motor and starter. In each case the cost of the complete driving unit, from the incoming ac supply to the motor coupling, has been included, but without any form of automatic control. To gain the full advantages of variable-speed pumping, it is essential to install an automatic control matched to the requirements of the system; but the additional cost of this control should be offset against savings in the cost of operating personnel.

The principle of operation of the ac variable-speed commutator motor suitable for driving variable-speed pumps is illustrated in Figures 9 and 10. The motor is basically a wound-rotor ac machine with the ends of the three rotor windings brought out to a commutator instead of slip rings. The commutator is simply a frequency-changing device and changes slip frequency in the rotor to the same frequency as the supply. Having obtained supply frequency from the rotor, the secondary of a variable-ratio transformer or induction regulator is connected in the rotor circuit, and the primary of the regulator is connected back to the supply. In Figure 9 the motor is running below synchronous speed; 100 hp is fed into the stator and across the air gap to the rotor. Fifty horsepower is used as work, while the remaining 50 hp is drawn off from the rotor through the regulator and returned to the supply. With the standard wound-rotor



A — Constant-Speed Wound-Rotor Motor — Cost 100%
B — Commutator Motor with Regulator — Cost 250%
C — DC Motor and Variable-Voltage Grid-Controlled Rectifier — Cost 350%
D — Constant-Speed Wound-Rotor Motor and Hydraulic or Magnetic Slip Coupling — Cost 175%
E — Wound-Rotor Motor with Liquid Rotor Resistance — Cost 125%

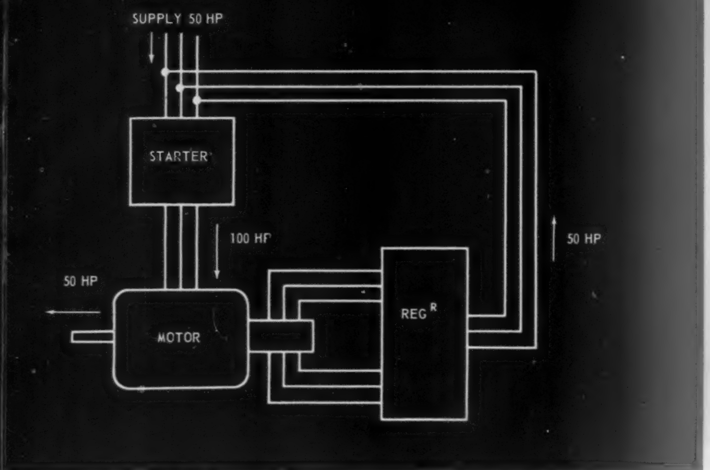
EFFICIENCY VERSUS SPEED is plotted for several variable-speed drives, using a 350/75 brake horsepower motor at 1200/720 rpm, when assuming a square law torque-speed relationship. **(FIGURE 8)**

machine the excess 50 hp is given up as heat in the rotor resistance. In Figure 10 the motor is running above synchronous speed; 100 hp is fed into the rotor via the stator, and an additional 50 hp is fed into the rotor through the regulator, thereby driving the rotor above synchronous speed. Therefore a total of 150 hp is available at the output shaft.

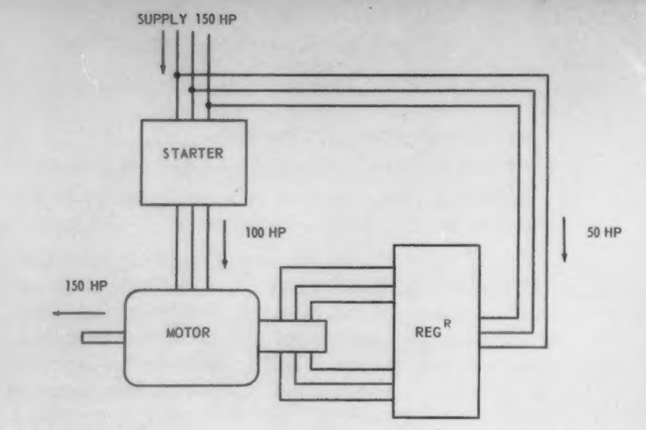
A variable-tap transformer can be used as a speed regulator. This transformer has the disadvantage that speed can be reduced only in finite steps, but power factors at all speeds and loads are comparable with constant-speed ac machines under corresponding partial loads. The induction type of regulator, which depends upon the angularity between the rotor and stator for its transformation ratio, has a stepless speed range, but because of the air gap, power factors fall off at low speeds and loads. The wattless load is, however, no greater than the wattless loads at the full speed, and if necessary, power factor correction capacitors can be used. The ac commutator motor has the disadvantage that, because of the inherent commutation difficulty, power and speed are limited to those generally found in dc machines. For the foregoing reason the motor is not usually suitable for boiler feed or other high speed pumps, without an intermediate step-up gear. The speed ranges required for boiler feed pumps are generally comparatively small, since the low frictional component of head is small. The commutator motor is most valuable where speed ranges from full speed down to about 60 or 70 percent are required.

Three pumps share load as demand varies

Control requirements for variable-speed pumps usually depend on either pressure or alternatively on system loss,



AC VARIABLE-SPEED commutator motor will return excess power to the supply when running below synchronous speed. **(FIGURE 9)**



AC VARIABLE-SPEED commutator motor will draw extra power from the regulator when running above synchronous speed. **(FIGURE 10)**

which is a function of flow, or most often a combination of both these factors.

The shaded area in Figure 11 shows the field of operation for a booster pumping station. The water demand in the pre-boosted area is certain to vary and affect the head available at the suction of the booster pumps. This condition is represented by a variation in static head between 75 and 100 ft. The static head would comprise the static head of the boosted area, plus the required residual pipe pressure, minus the pressure available at the suction side of the pumps. From a study of standard pump characteristics and of the proportion of frictional head to total head, after taking into account the initial cost of plant, it is found that most efficient operation is obtained with three pumps. With the extreme case of a wholly frictional head one pump would ideally cover the field, since the system curve could lie on the point of best pump efficiency from zero to maximum quantity.

For most efficient running, the sequence of operation would be as follows:

(*a*) The first pump would be started by a pressure switch in the event of low pressure in the suction pipe which would further reduce the pressure in this pipe and give an inherently stable form of control. The starting speed would be 60 percent speed and would gradually increase to 77 percent speed as demand increases.

(*b*) When No. 1 pump reaches 77 percent speed, No. 2 pump would cut in and speed up, and at the same time No. 1 pump would be retarded until the two speeds matched and the two pumps together delivered the same quantity as the first pump at 77 percent speed. As demand increases the two pumps would then increase speed together until about 82.5 percent speed.

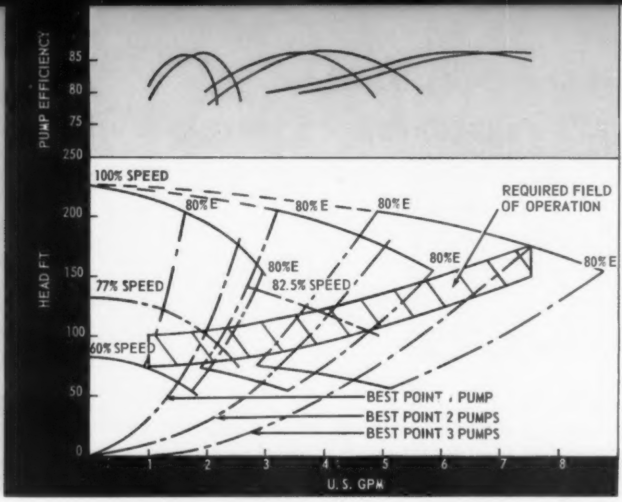
(*c*) At 82.5 percent speed, the two pumps can no longer meet the demand efficiently, and at this point the third pump would be cut in and increase in speed; simultaneously pumps Nos. 1 and 2 would decrease in speed until the three speeds matched and the three pumps in parallel delivered the desired quantity. Again as demand increases the three pumps would increase speed together to give full capacity operation.

System demand regulates motor speed

One of many possible control systems which would control three pumps according to load demands is shown in Figure 12. It is assumed that the pressure at the end of the boosted system must be kept constant. To accomplish this, it is necessary to measure the pressure at the pump house and deduct from this the frictional pressure loss in the system. If this resultant is kept constant, then the pressure at the end of the system will be constant. Since the pressure loss in a system is approximately proportional to the square of the velocity and the differential across a Venturi is also proportional to the square of the velocity, then the differential will be in proportion to the pressure loss. The Venturi meter *F* would therefore have a linear electrical output with differential, and this value would be deducted from the electrical output of a pressure sensitive device *P* by the simple computer shown at the right of the diagram. The weight of flow and pressure on the control system can be adjusted by means of *HS1* and *HS2,* respectively, and the net amount would be balanced against *HS3,* which corresponds to the required residual pressure at the end of the pipeline.

All *HS* controls would be hand set at the site to provide the best operating characteristics. The balance beam *B* will detect any out of balance between the three forces and operate the pilot motor *PM* on No. 1 pump regulator *R* to raise or lower the speed of the main motor. As soon as the head-quantity relationship satisfies the demand, as detected by the computer, the balance beam will return to its mid-position, the pilot motor will stop, and the main motor will run at its new speed. To prevent the control hunting and producing hydraulic surges, a timer *T* is introduced having a variable "make" period and a variable "break" period, so that the control is temporarily cut off to allow conditions to stabilize before a further change is made. Hydraulic surges can also be prevented by choosing suitable gearing between pilot motor *PM* and the speed regulator *R,* thus limiting the acceleration of the pump. As soon as No. 1 pump reaches a preset speed, as determined by a limit switch on No. 1 regulator, this would in turn start No. 2 pump.

Most efficient operation requires that pump No. 2 runs at the same speed as pump No. 1. This can be achieved by using a differentially connected double element wattmeter *W*. The first element would measure the power input to pump No. 1; the second element, the power input to pump No. 2. If the two powers balance, the needle will stay in the mid-position; if No. 1 is running faster than



VARIABLE-SPEED PUMPS match demand at high efficiency throughout field of operation, as indicated by shaded area. **(FIGURE 11)**

No. 2, then the contact will "make" and increase the speed of pump No. 2 by controlling the pilot motor *PM* on No. 2 regulator *R*. As many pumps as required can be added. The power input to each pump is compared and matched to the power input to No. 1 pump, which is the master unit under direct control from the pipeline.

In practice it is necessary to introduce a plug selector board or multi-position switch, so that first, second, and third duty pumps can be changed to prevent the major load being continually carried by one pump.

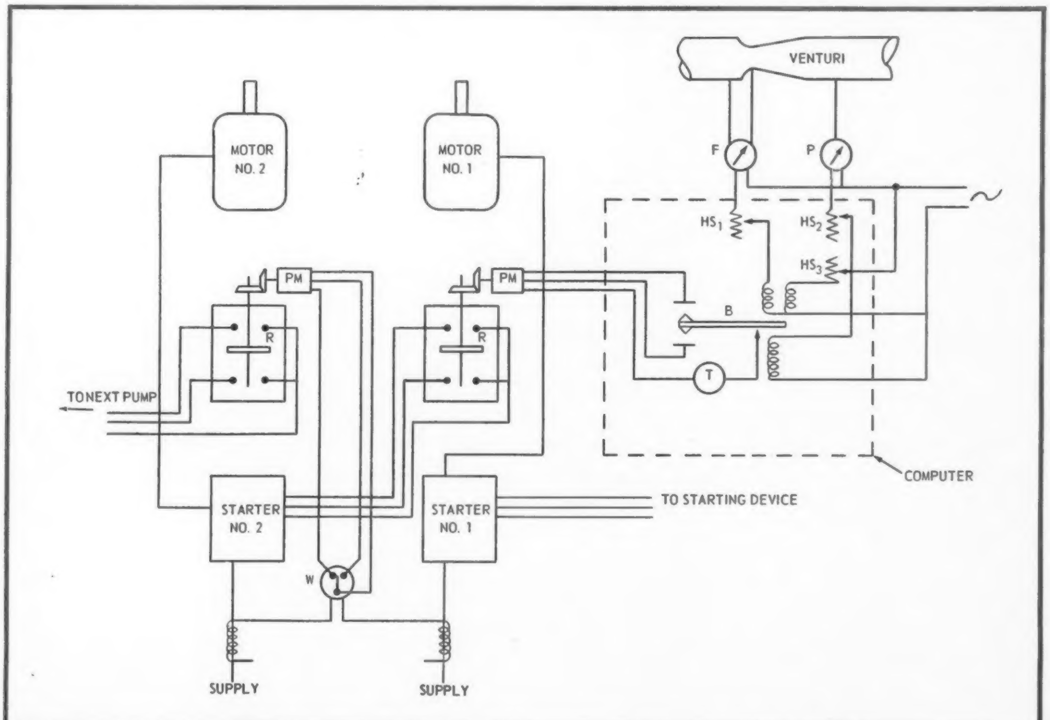
It is possible to provide the pump motors with tacho-generators and compare voltage outputs in order to match the speed of the pumps as an alternative to the double element wattmeter method described above. The double element wattmeter has the advantage, however, in that the pumps will share the load equally in spite of possible small differences in head-quantity output at a given speed.

The control system for pumps emptying a sump would comprise a level sensitive device or transmitter such as a float geared to a variable resistance, with the electrical output compared to a preset value similar to *HS3* in Figure 8. High and low level contacts built into the level transmitter would start and stop the master pump.

If desired, pneumatic or a combination of pneumatic and hydraulic controls can be used instead of an electrical control, but generally these are not nearly so flexible or adaptable. With this type of control, the speed regulator would be operated directly from a hydraulic power cylinder.

Variable-speed motors offer a challenge

It is not feasible to consider every type of system in detail from both the economic and control standpoint, but some of the general variable-speed pump applications have been considered. However, the merits of each application must be analyzed individually to arrive at the most efficient pump and motor combination. Variable-speed pumps and motors with the special form of control required will undoubtedly cost more initially than a constant-speed plant, but with careful application the extra cost may be recovered in as little as four or five years.



CONTROL DIAGRAM is one of many circuits necessary for automatic speed operation with conditions of Figure 11. **(FIGURE 12)**

5 Cases of Reflected Waves from Discharging Arresters

by A. H. KNABLE
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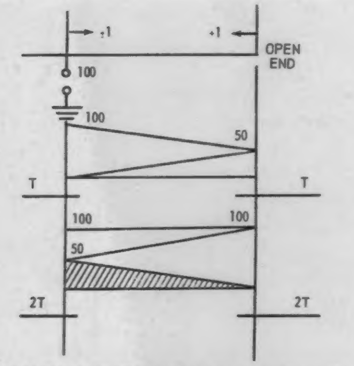
IN DEALING WITH PROBLEMS on maximum voltage, an analysis of a surge voltage build-up ceases when the arrester sparkover voltage is reached. If, however, the wave shape as well as magnitude is desired in an analysis, the surge voltage must continue into the arrester sparkover period. To make this analysis, the behavior of surges at the junction of discharging arresters must be known. The sketches of the following five cases depict this behavior. These five cases are broad enough to make an idealized analysis of practical problems.

It should be noted in Case IV and Case V that the splitting of the reflected portion of the wave into two parts permits the tracing of the wave as though it were two simple distinct waves.

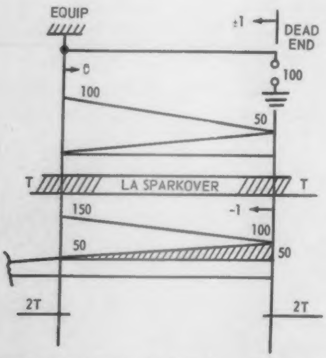
The problem of how wave shape at the end of a line varies with the line length to an arrester for a given incoming wave can be analyzed by the approach shown in Case I. This analysis can then be used in conjunction with a volt-time curve of the equipment insulation to obtain the margin of safety between applied and breakdown voltage.

REFERENCE

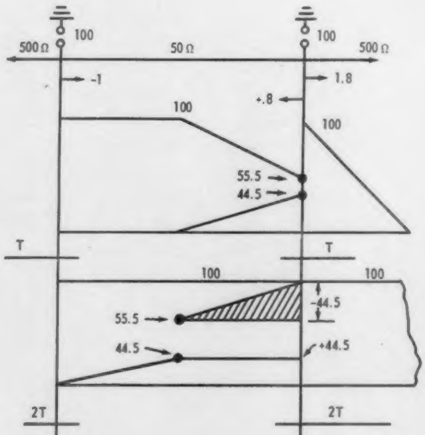
"Short Cuts in Surge Analysis," by A. H. Knable, 1st Quarter, 1957 *Allis-Chalmers Electrical Review.*



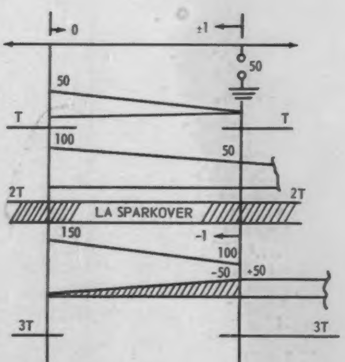
REFLECTION OPERATOR changes from +1 to —1 before any reflection phenomena occur when the arrester discharges before the first reflection arrives. **(CASE I)**



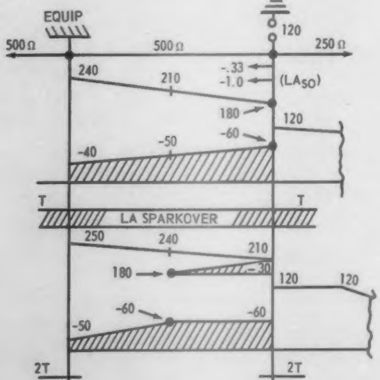
REFLECTION OPERATOR changes from +1 to —1 in middle of positively reflected wave when arrester discharges after wave has reflected from the arrester. **(CASE II)**



REFLECTION OPERATOR changes from +1 to —1 in the middle of a positively reflected wave when arrester discharges after wave has been partially reflected from arrester. **(CASE V)**



REFLECTION OPERATOR changes from +1 to —1 in the middle of a through wave when the arrester discharges after the wave has partially passed by the arrester. **(CASE III)**



REFLECTION OPERATOR changes from +1 to —1 in the middle of a negatively reflected wave when arrester discharges after wave has been partially reflected from the arrester. **(CASE IV)**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